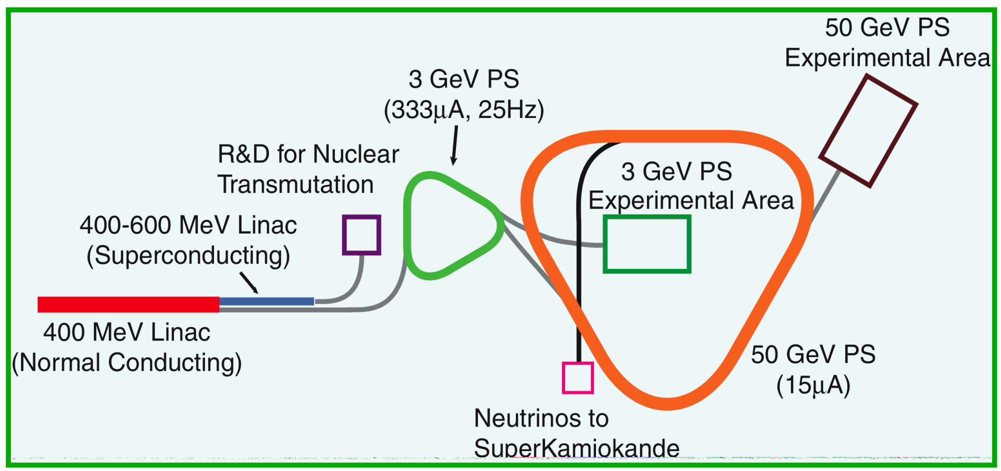
Search for New Physics via not so rare K^+ Decay Experiments at J-PARC

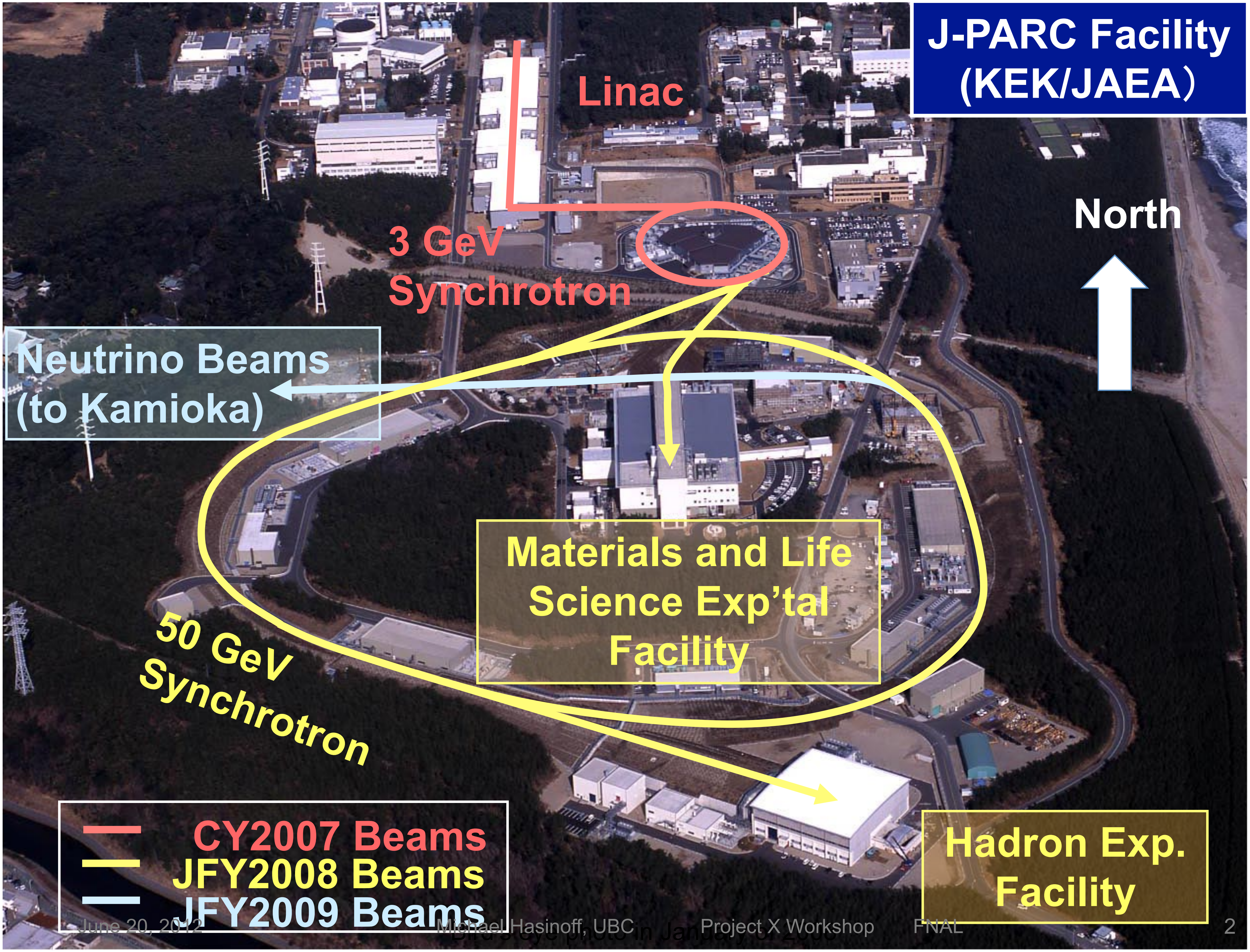
Michael D. Hasinoff
University of British Columbia
on behalf of the TREK collaboration

Outline

- **Hadron Facility at J-PARC**
- **TREK Program** TREK = Time Reversal Experiment with Kaons
  - **Search for Time Reversal Symmetry Violation**
  - **Test of Lepton Universality**
  - **Search for Heavy Neutrinos**

  Lower intensity
- **TREK Apparatus -- R & D**
- **Status & Schedule**

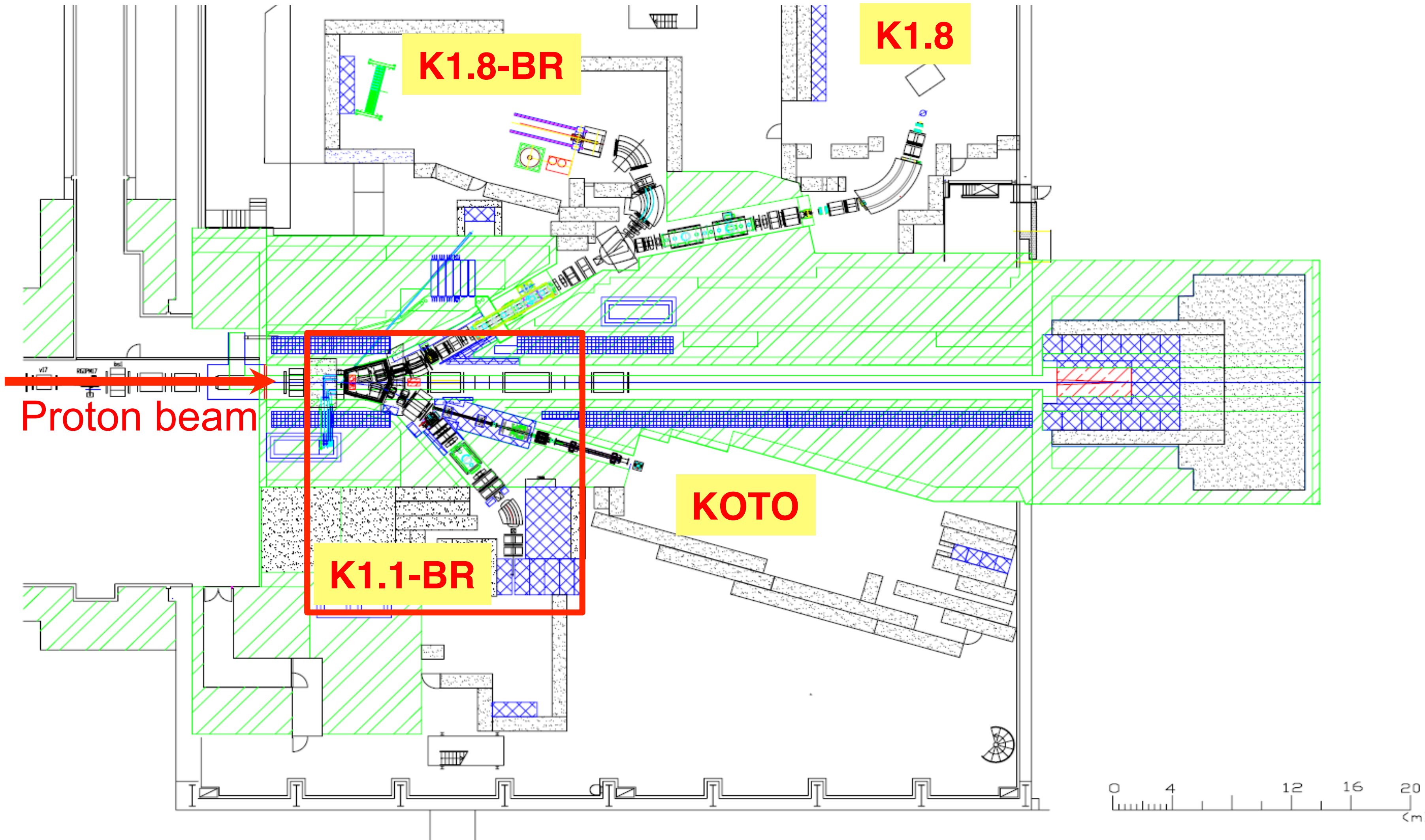



J-PARC Facility
(KEK/JAEA)
Linac
3 GeV
Synchrotron
North
Neutrino Beams
(to Kamioka)
Materials and Life
Science Exp'tal
Facility
50 GeV
Synchrotron
Hadron Exp.
Facility
CY2007 Beams
JFY2008 Beams
JFY2009 Beams

J-PARC Mar 2011 Earthquake Damage

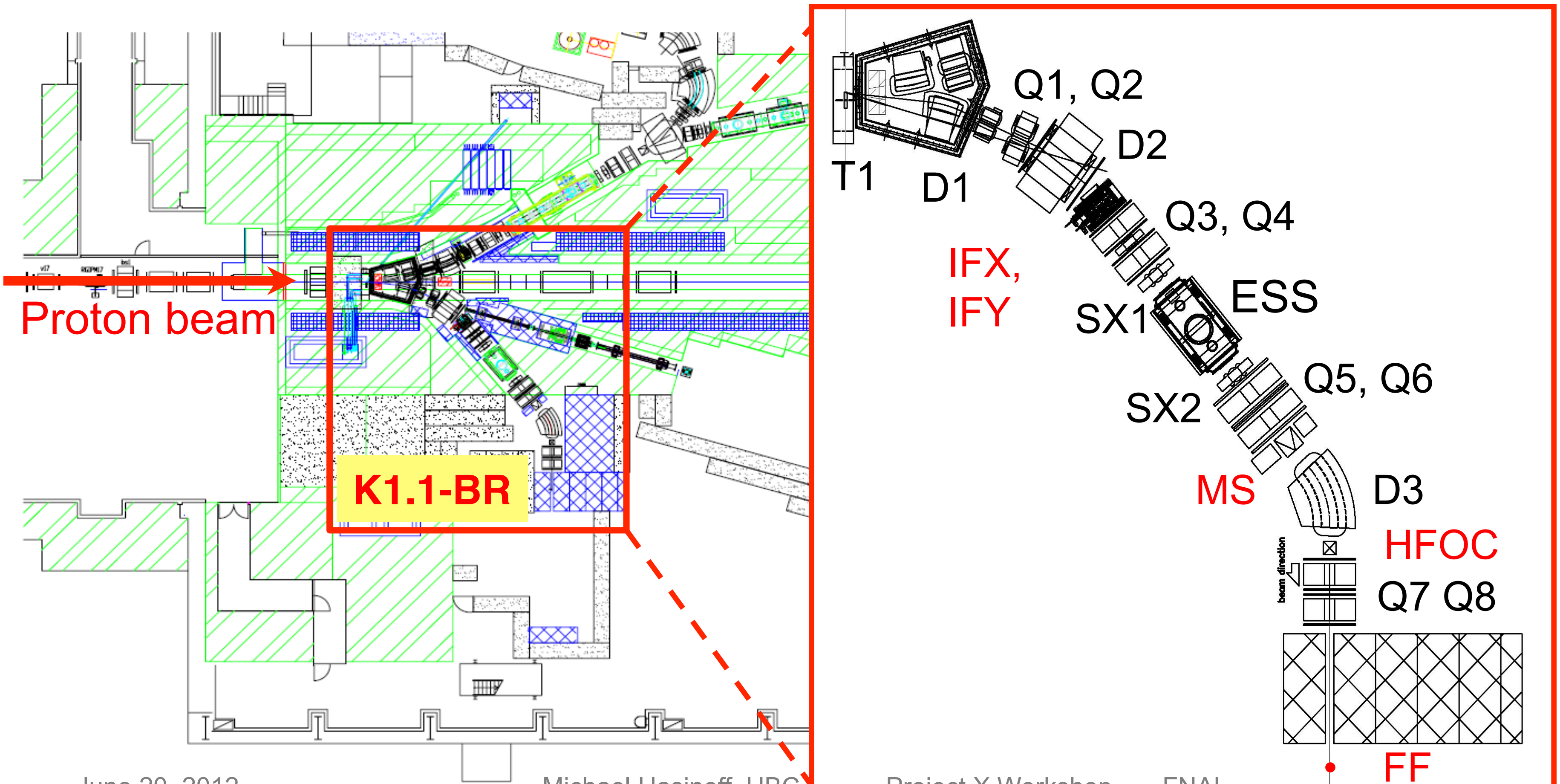
K1.1BR = K0.8 Beam Line Installation

- K1.1BR completed in summer 2010 using the supplementary budget of FY09
- Commissioned in Oct. 2010 by the TREK collaboration



K1.1BR = K0.8 Beam Line Installation

- K1.1BR completed in summer 2010 using the supplementary budget of FY09
- Commissioned in Oct. 2010 by the TREK collaboration
  - ESS Length of 2.0m to be increased to 2.5m
  - Length Q8-FF of 3.3m to be reduced to 1.5m (remove iron shielding wall)



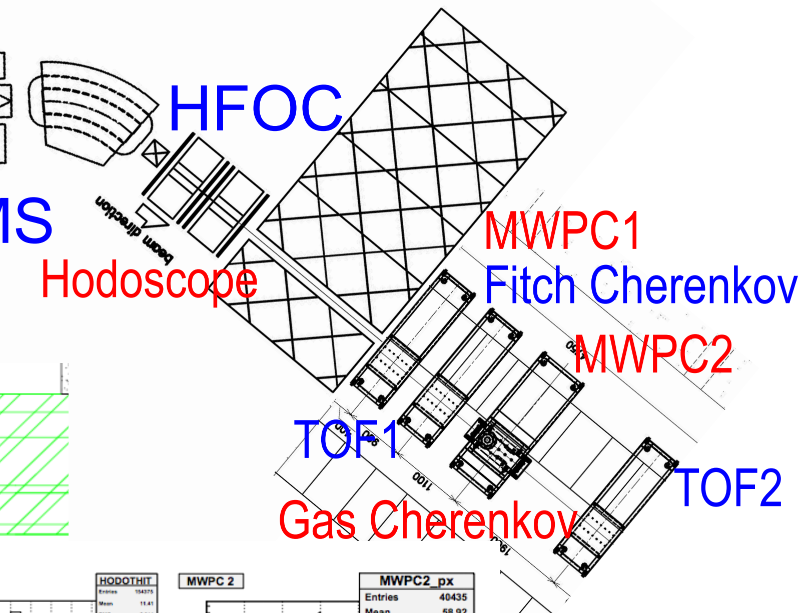
Low-p K^+ beam at K1.1BR

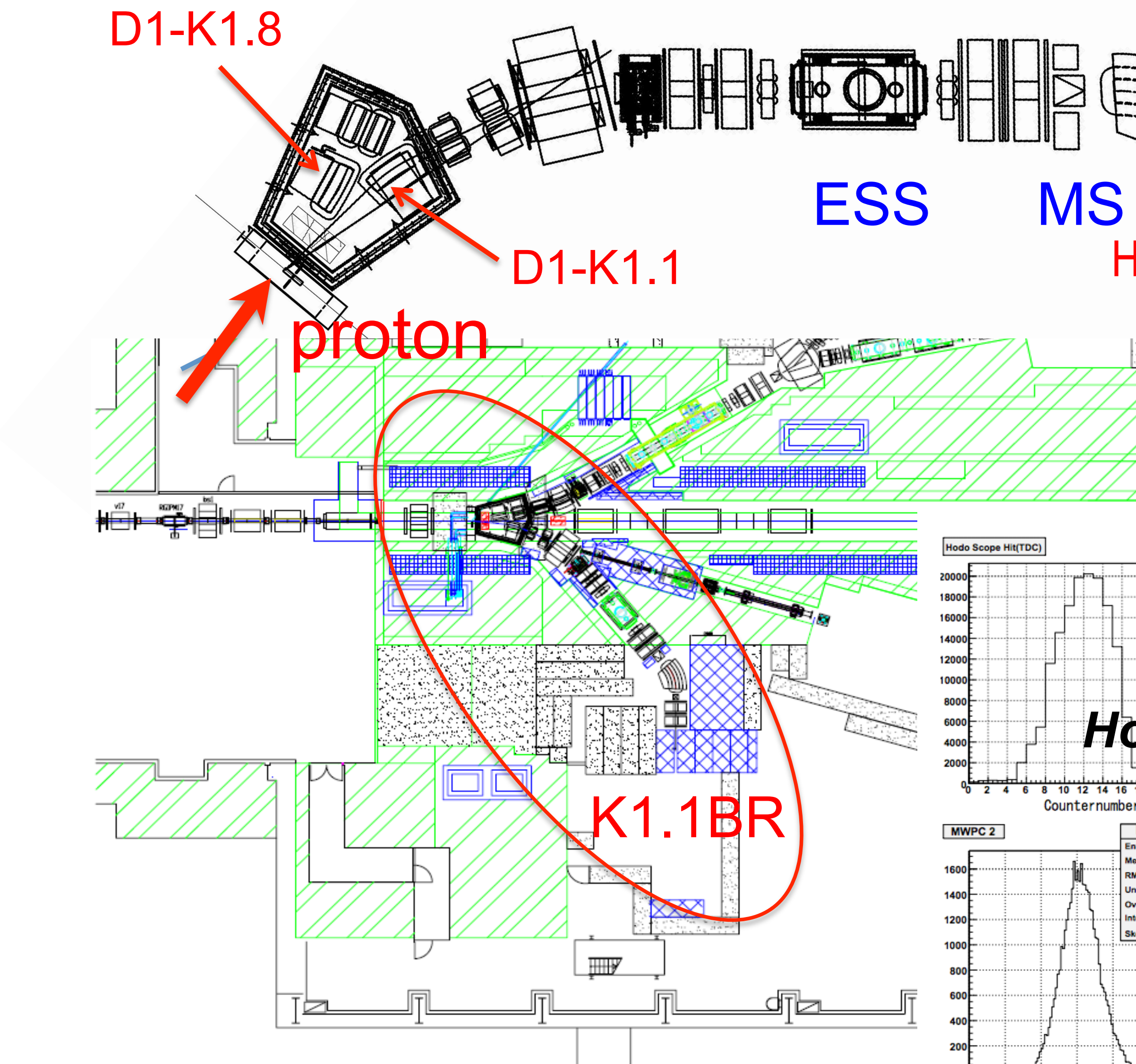
- Optics design by J.Doornbos (TRIUMF)
  - Based on the IFY concept by Dr. H. Noumi
  - Effective suppression of the cloud pions
  - Under the given conditions at the T1 target (K1.8 priority)
  - Possible future extension to K1.1
- Low acceptance compared with other LE beamlines, but we can still use our low rate CsI(Tl) detector

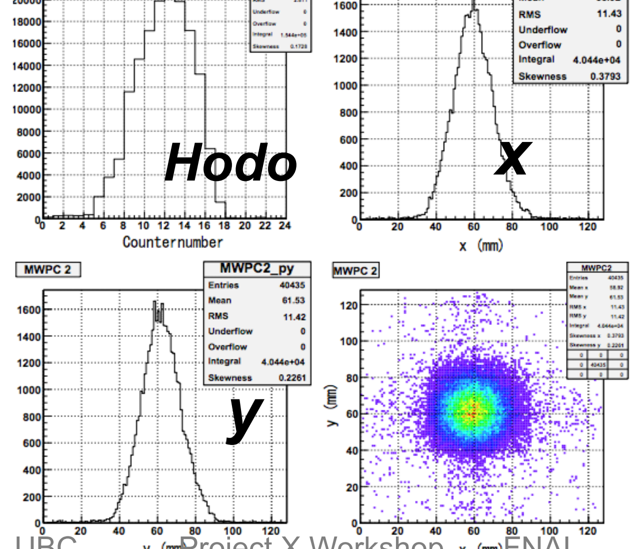
Beam	Extraction (degree)	Momentum (GeV/c)	Acceptance (msr %)	Length (m)	ES separator (Stage)	Comment
K1.1BR	6	0.8	4.6	20.3	single(+IFY)	rad hard
LESB-III (AGS)	0	0.8-0.71	48	19.6	double	requires high rate detectors
FNAL (design)	0	0.55	120	13.7	double	

K1.1BR beam commissioning

Oct.-Nov. 2010





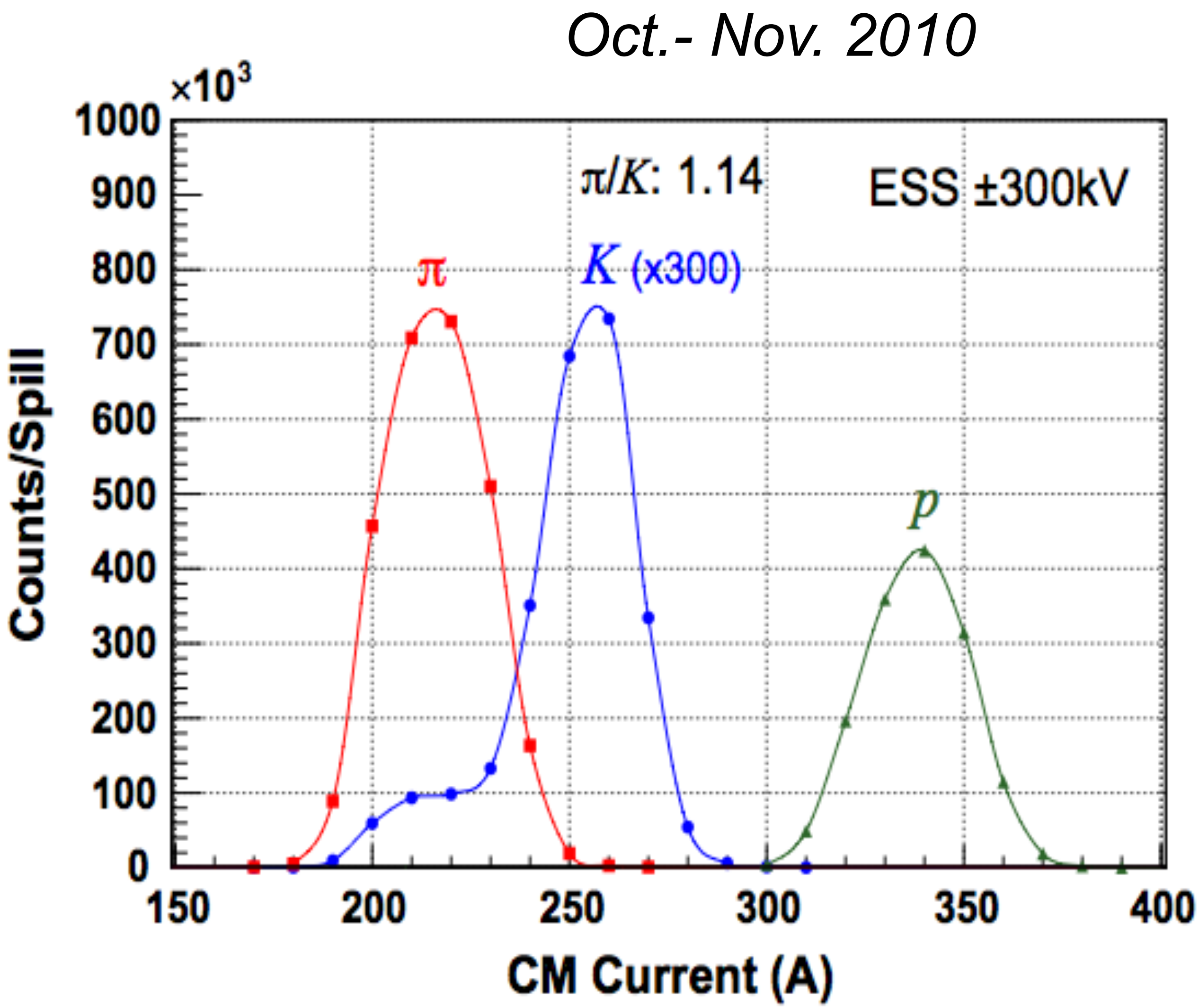


Beam spot at MWPC2

σx = 11 mm

σy = 11 mm

K1.1BR beam line performance

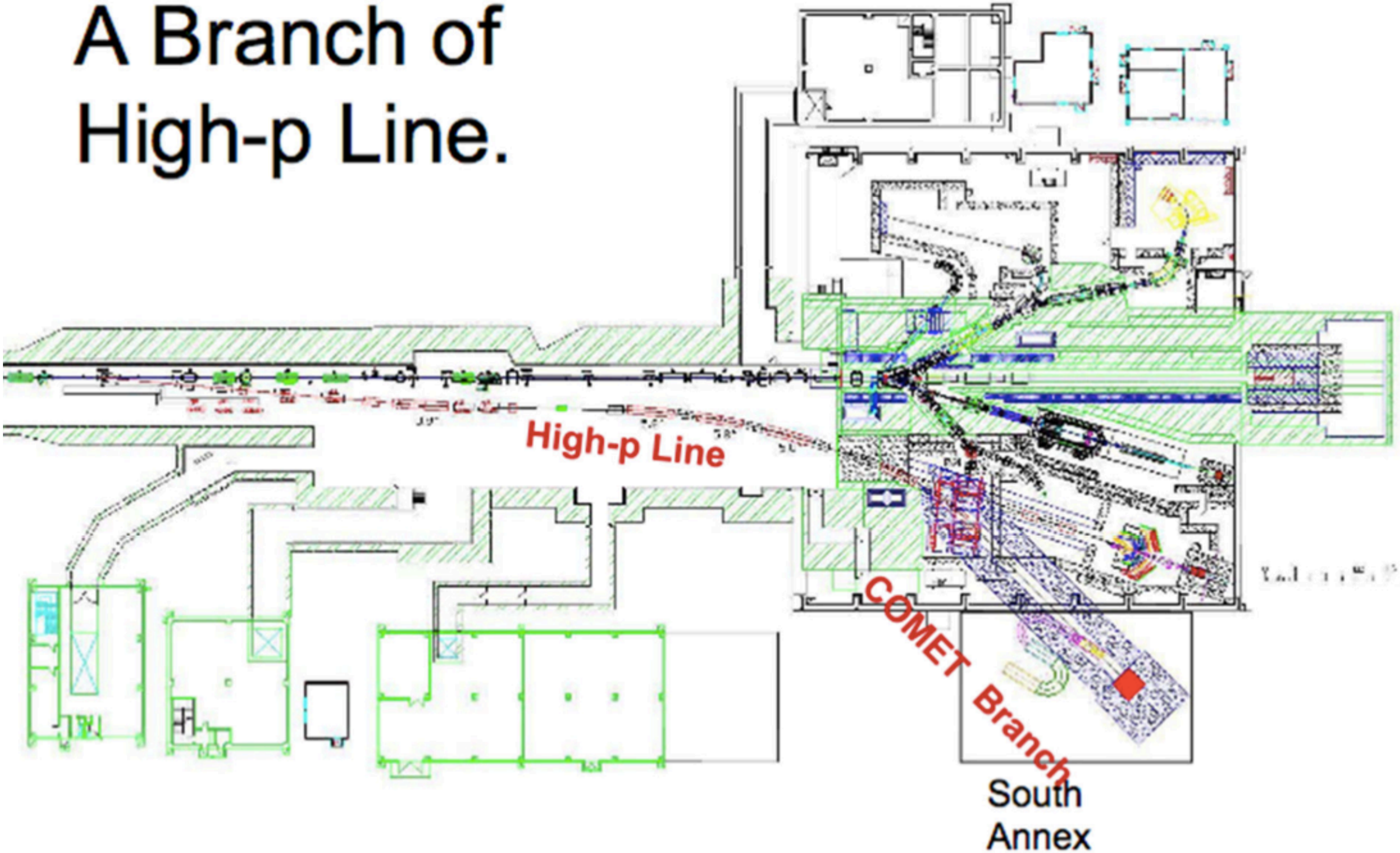


Pt target
p_0 = 800 MeV/c
ESS = ±300 kV
H. slits = wide open
π/K ratio = 1.14
K^+ yield : ~OK

Setting of:
Q3/Q4 & Q5/Q6
as optics design

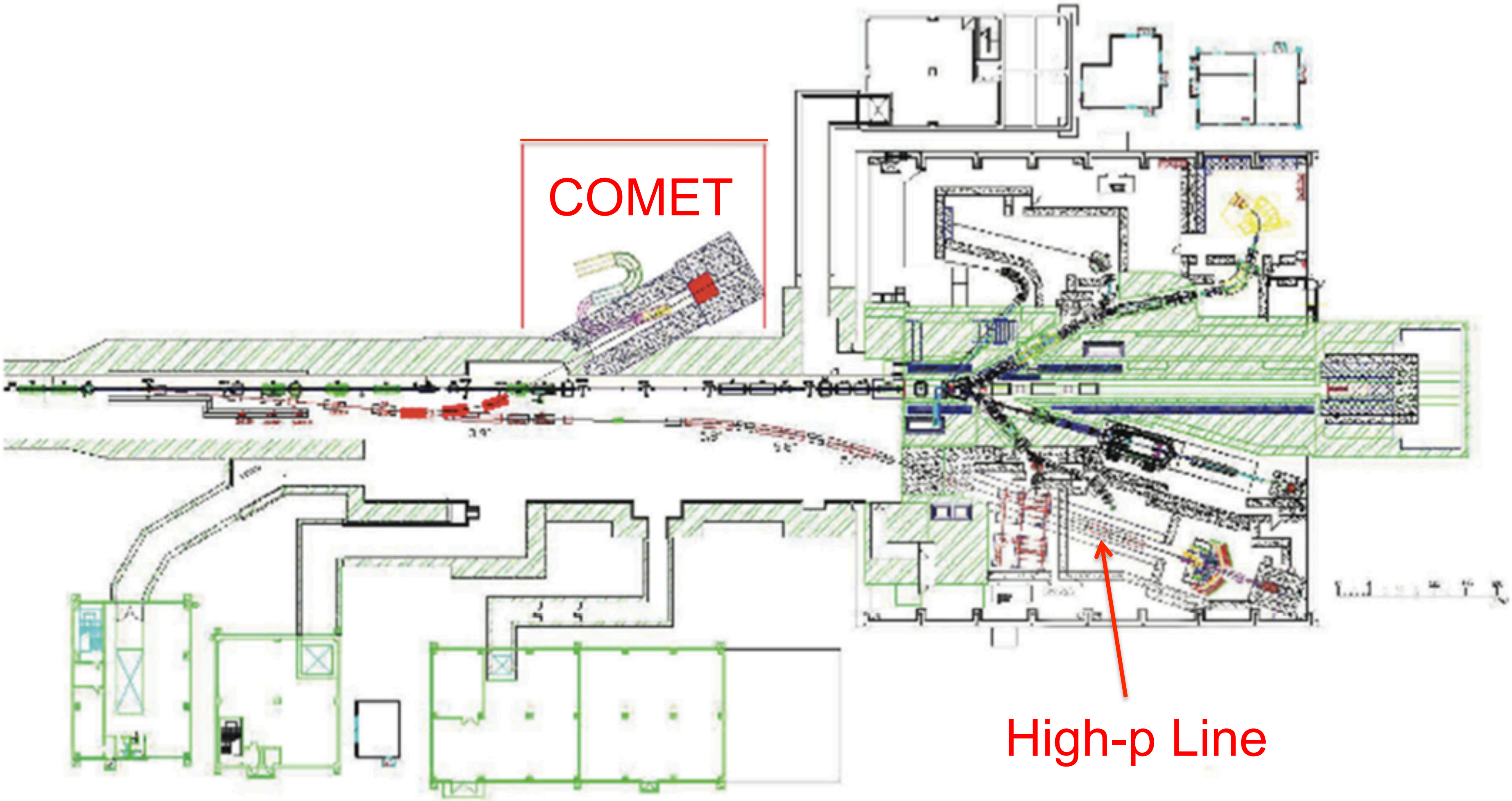
~ 6 × 10⁴ /spill @ 3.6 kW for the standard slit opening

COMET Beam Line for mu-e Exp. A Branch of High-p Line.



Another possible option of the COMET line

-- this does not share as many of the high-p line magnets
but it would allow K1.1BR to remain in place



Stopped K^+ Experiments @ K1.1BR

- E06 (TREK)

  "Measurement of the T-violating transverse muon polarization (P_T) in $K^+ \rightarrow \pi^0 \mu^+ \nu$ decay"

  Stage-1 approved needs 270 kW (≥ 100 kW)

- P36 (LFU)

  "Measurement of $R_K = \Gamma(K^+ \rightarrow e^+\nu) / \Gamma(K^+ \rightarrow \mu^+\nu)$ and search for heavy sterile neutrinos"

  Stage-1 recommended (PAC11-Jan'11) only 30 kW

TREK Collaboration

CANADA

University of British Columbia
University of Manitoba
Université de Montréal
University of Saskatchewan
TRIUMF

USA

Hampton University
T. Jefferson Nat. Laboratory
Iowa State University
University of South Carolina

RUSSIA

Russian Academy of Sciences (RAS)
Institute for Nuclear Research (INR)--Moscow

JAPAN

Osaka University
National Defense Academy
Tohoku University
High Energy Accelerator Research Org. (KEK)
Chiba University
Kyoto University
Tokyo Institute of Technology (TITech)
University of Tokyo

VIETNAM

University of Natural Sciences

New collaborators are welcome!

Physics of E06: $K_{\mu 3}$ T violation (TREK)

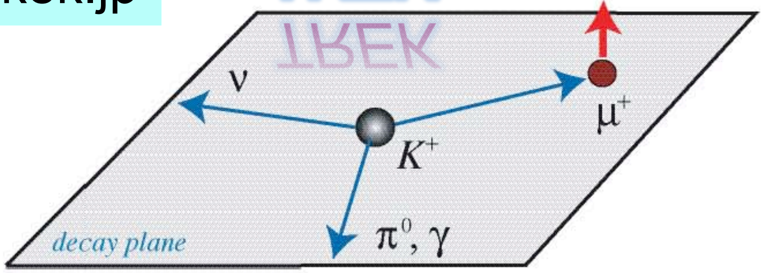
Transverse μ^+ polarization in $K_{\mu 3}$ Decay

$K^+ \to \pi^0 \mu^+ \nu$ decay

http://trek.kek.jp

TREK

$$P_T = \frac{\sigma_\mu \cdot (p_{\pi^0,\gamma} \times p_{\mu^+})}{|(p_{\pi^0,\gamma} \times p_{\mu^+})|}$$



- P_T is T-odd, and spurious effects from final state interaction are small: $P_T(\mathrm{FSI}) < 10^{-5}$

  Non-zero P_T is a signature of T violation.

- Standard Model (SM) contribution to P_T : $P_T(\mathrm{SM}) < 10^{-7}$

  Hence P_T in the range 10^{-3} – 10^{-5} is a sensitive probe of CP violation beyond the SM.

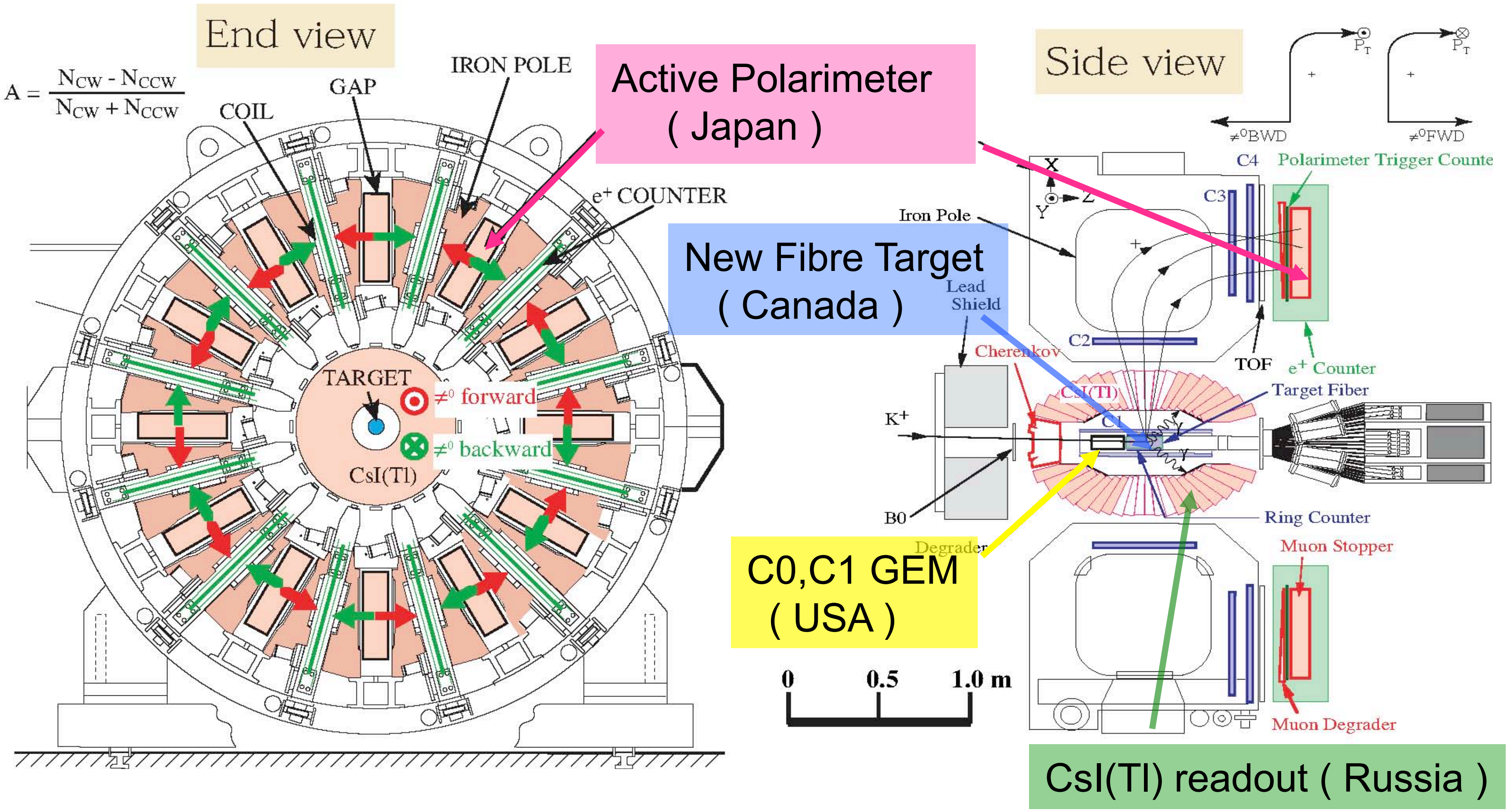
- There are many theoretical models of new physics which allow a sizable P_T value without conflicting with other experimental constraints.

The TREK experiment aims for a sensitivity of 10^{-4}

TREK Experimental Apparatus

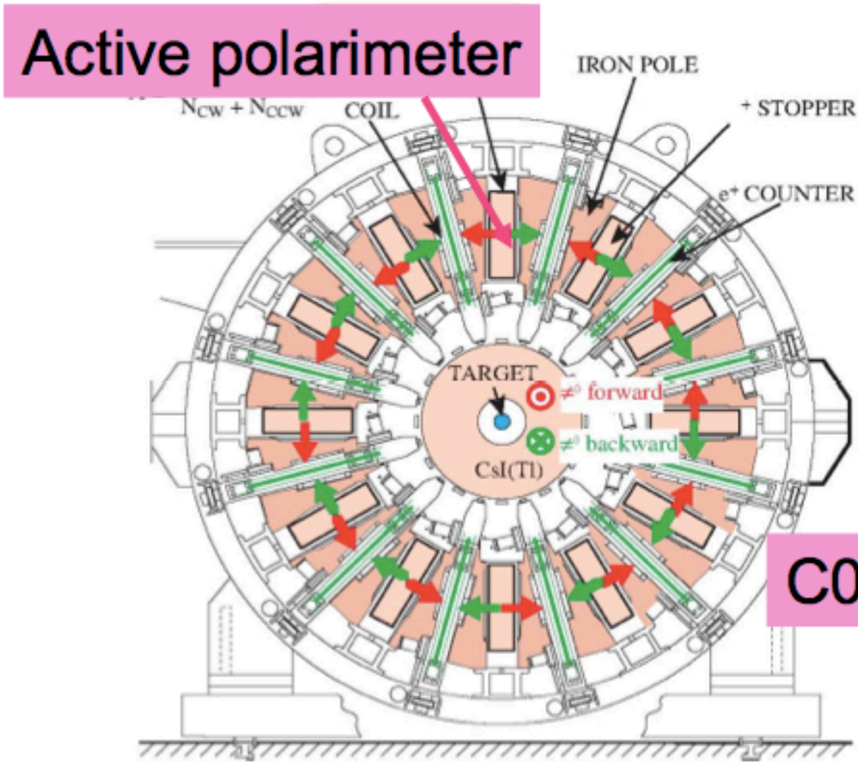
$K^+ \rightarrow \pi^0 \mu^+ \nu$

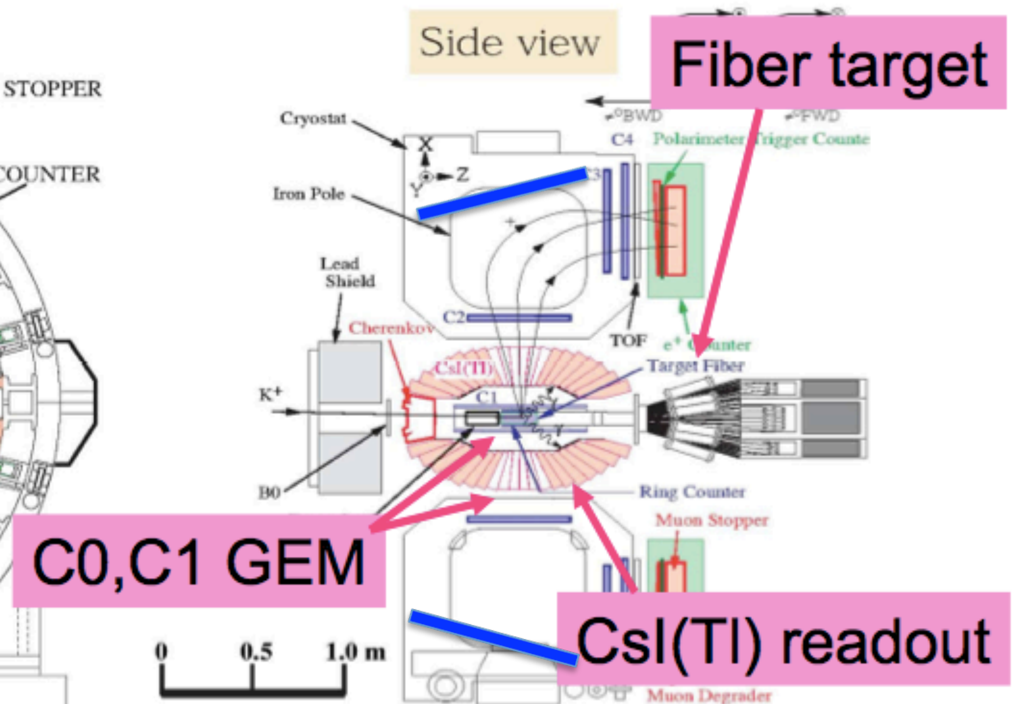
Use an upgraded E246 detector



P_T is measured as the azimuthal asymmetry A_e^+ of the μ^+ decay positrons

Upgraded E246 detector





- Target --- Canada
- GEM --- USA
- CsI(Tl) readout --- Russia
- Polarimeter、AC --- Japan

Stopped beam method $K^+ \rightarrow \pi^0 \mu^+ \nu$

Double ratio experiment

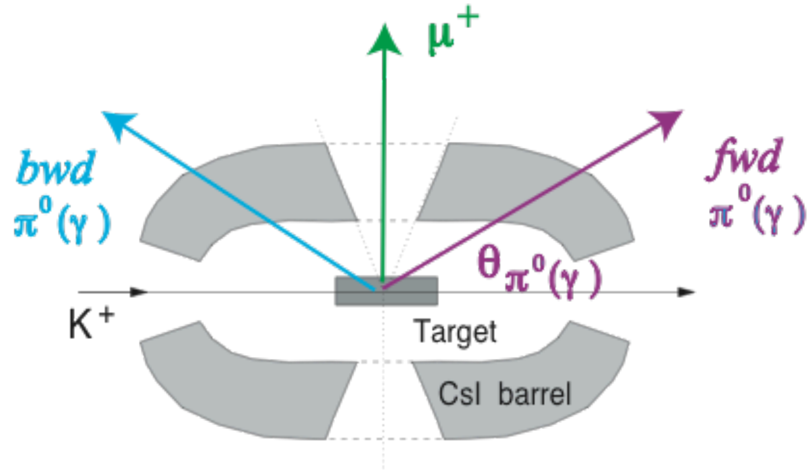
$A_T = (A^{fwd} - A^{bwd}) / 2$

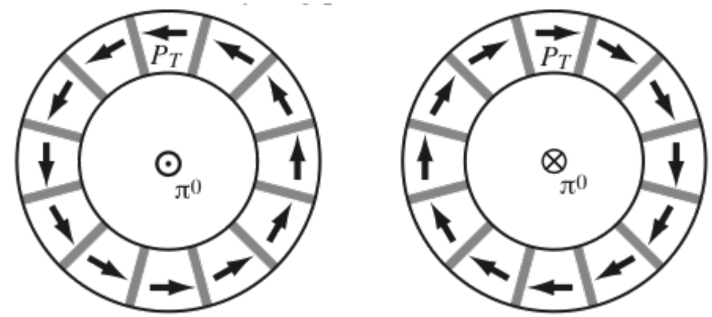
$$A^{fwd(bwd)} = \frac{N_{cw} - N_{ccw}}{N_{cw} + N_{ccw}}$$

$P_T = A_T / \{\alpha \langle\cos\theta_T\rangle\}$

α : analyzing power
$\langle\cos\theta_T\rangle$: attenuation factor

$\mathrm{Im}\xi = P_T / KF$: physics parameter
KF : kinematic factor





bwd - π^0 (γ) **fwd** - π^0 (γ)

Current limit from KEK--E246

$P_T = -0.0017 \pm 0.0023(stat) \pm 0.0011(syst)$

$|P_T| < 0.005$: 90% C.L.

$\mathrm{Im}\xi = -0.0053 \pm 0.0071(stat) \pm 0.0036(syst)$

$|\mathrm{Im}\xi| < 0.016$: 90% C.L.

Statistical error dominates

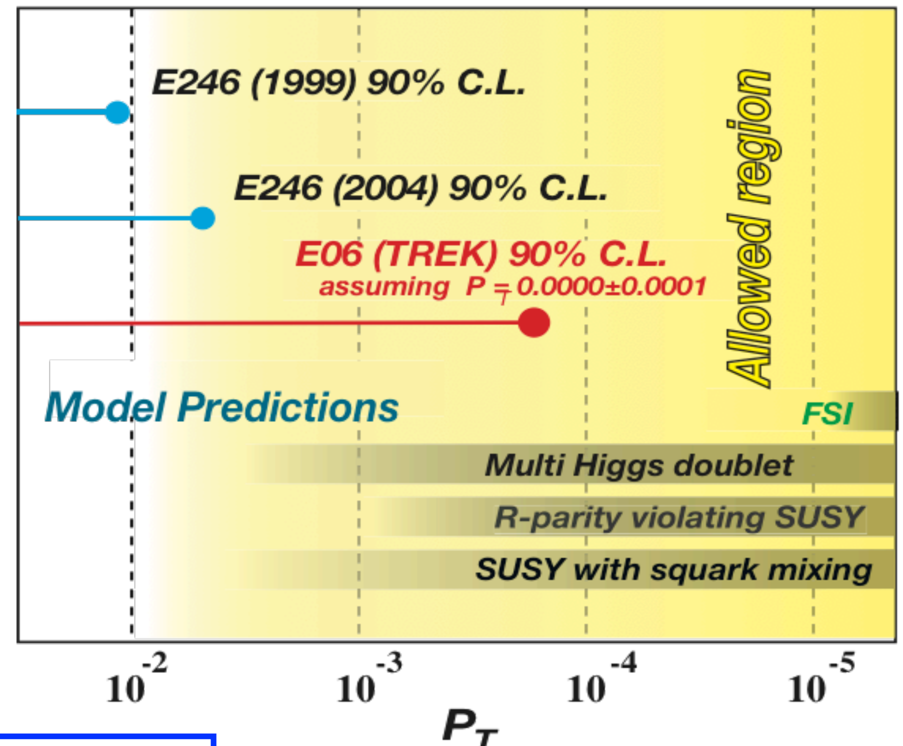
Expected sensitivity -- TREK

We are aiming for a sensitivity of $\delta P_T \sim 10^{-4}$

δP_T^{stat} (TREK) $\sim 0.05\ \delta P_T^{stat}$ (E246) $\sim 10^{-4}$

$\sim 1.4 \times 10^7$ sec runtime

1) Beam intensity x 30
2) Detector acceptance x 10
3) Larger analyzing power

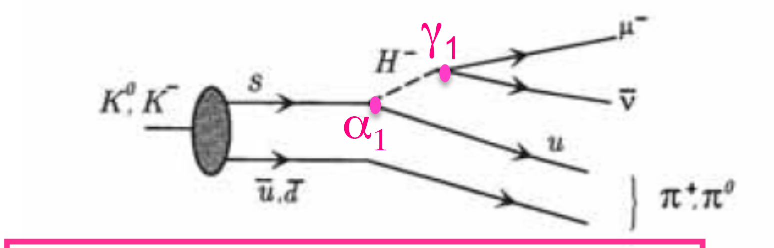


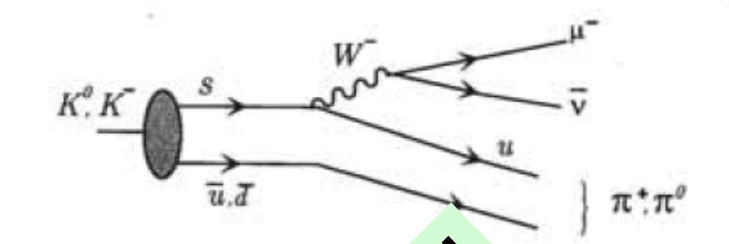
$\delta P_T^{syst} \sim 10^{-4}$

1) Precise calibration of misalignments
2) Correction of systematic effects
3) Precise ***fwd-bwd*** cancellation

Three Higgs doublet model

$$L = (2\sqrt{2}G_F)^{\frac{1}{2}} \sum_{i=1}^{2} \{\alpha_i \bar{u}_L V M_D d_R H_i^+ + \beta_i \bar{u}_R M_U V d_L H_i^+ + \gamma_i \bar{\nu}_L M_E e_R H_i^+\} + \text{h.c.},$$





$$\mathrm{Im}\xi = \frac{m_K^2}{m_H^2}\mathrm{Im}(\gamma_1 \alpha_1^*)$$

- c.f. d_n , $b \to s\gamma$ $\propto$ Im($\alpha_1\beta_1$*), ($\alpha_1\beta_1$*)

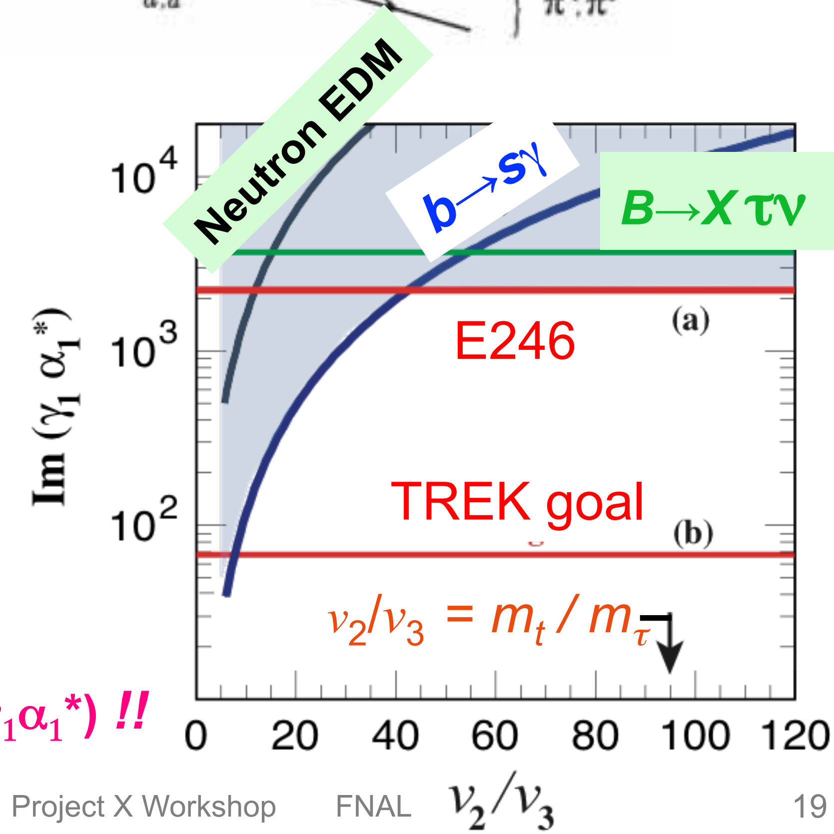
  Im($\alpha_1\beta_1$*) = $\underline{-v_2^2/v_3^2}$ Im($\gamma_1\alpha_1$*)

  Higgs field v.e.v.

- *B*→*X*τν and *B*→τν at Super-Belle corresponds to $P_T < 3 \times 10^{-4}$

  c.f. TREK goal : $P_T \leq 1 \times 10^{-4}$

P_T is most stringent constraint for* Im($\gamma_1\alpha_1$*) *!!



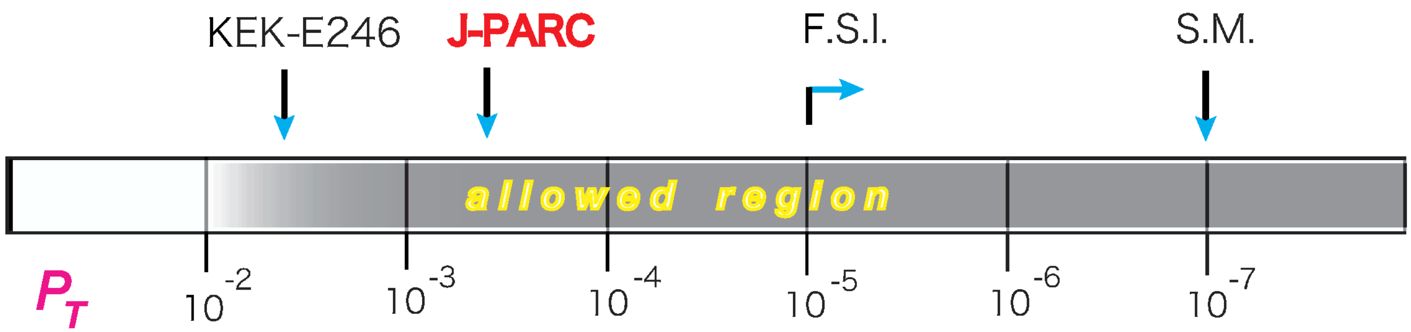
Comparison with P_T in $K_{\mu\nu\gamma}$

Kobayashi, Lin and Okada; Prog. Theor. Phys. 95, 361 (1995)

	$K_{\mu 3}$ $(K^+ \to \pi^0 \mu^+ \nu)$	$K_{\mu\nu\gamma}$ $(K^+ \to \mu^+ \nu \gamma)$
P_T origin interfering with G_F	G_S **(scalar)**	G_P, $G_R = (G_V + G_A) / 2$ **(pseudoscalar & right-handed)**
$< P_T > \; =$	$\sim 0.3 \text{ Im } \Delta_S$ $\text{Im } \Delta_S = \dfrac{\sqrt{2}(m_K^2 - m_\pi^2) \text{ Im } G_S^*}{(m_s - m_u) m_\mu G_F \sin\theta_C}$ $= 2 \text{ Im}\xi$	$\sim 0.1 \text{ Im } \Delta_P + 0.3 \text{ Im } \Delta_R$ $\text{Im } \Delta_P = \dfrac{\sqrt{2}\, m_K^2 \text{ Im } G_P}{(m_s + m_u) m_\mu G_F \sin\theta_C}$ $\text{Im } \Delta_R = \dfrac{\sqrt{2} \text{ Im } G_R}{G_F \sin\theta_C}$

Measurements of both can discriminate between models

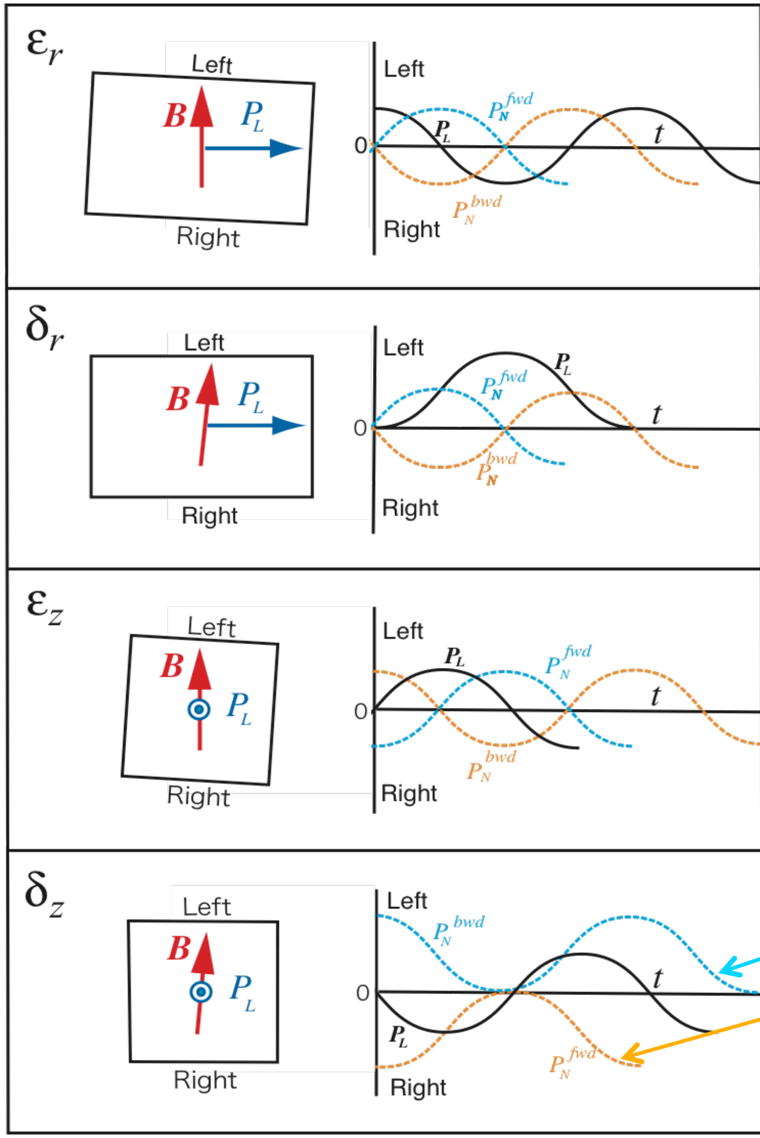
New Physics: Model predictions for P_T



Model	$K^+ \to \pi^0\mu^+\nu$	$K^+ \to \mu^+\nu\gamma$
■ Standard Model	$< 10^{-7}$	$< 10^{-7}$
■ Final State Interactions	$< 10^{-5}$	$< 10^{-3}$
■ Multi-Higgs	$\leq 10^{-3}$	$\leq 10^{-3}$
	$P_T(K^+ \to \pi^0\mu^+\nu) \approx +3\, P_T(K^+ \to \mu^+\nu\gamma)$	
■ SUSY with squark mixing	$\leq 10^{-3}$	$\leq 10^{-3}$
	$P_T(K^+ \to \pi^0\mu^+\nu) \approx -3\, P_T(K^+ \to \mu^+\nu\gamma)$	
■ SUSY with *R*-parity breaking	$\leq 4 \times 10^{-4}$	$\leq 3 \times 10^{-4}$
■ Leptoquark model	$\leq 10^{-2}$	$\leq 5 \times 10^{-3}$
■ Left-Right symmetric model	0	$< 7 \times 10^{-3}$

Most serious systematic error

- Analysis with MC simulations -



e^+ asymmetry due to polarimeter misalignment

	Rotation about	
Component	*r*-axis	*z*-axis
Polarimeter	ε_r	ε_z
Muon B field	δ_r	δ_z

fwd - ***bwd*** : vanishes for ε_r , ε_z , δ_r when *t*-integrated

fwd - ***bwd*** : does **not** vanish for δ_z !

- *Innovative analysis method to separate misalignment effects*

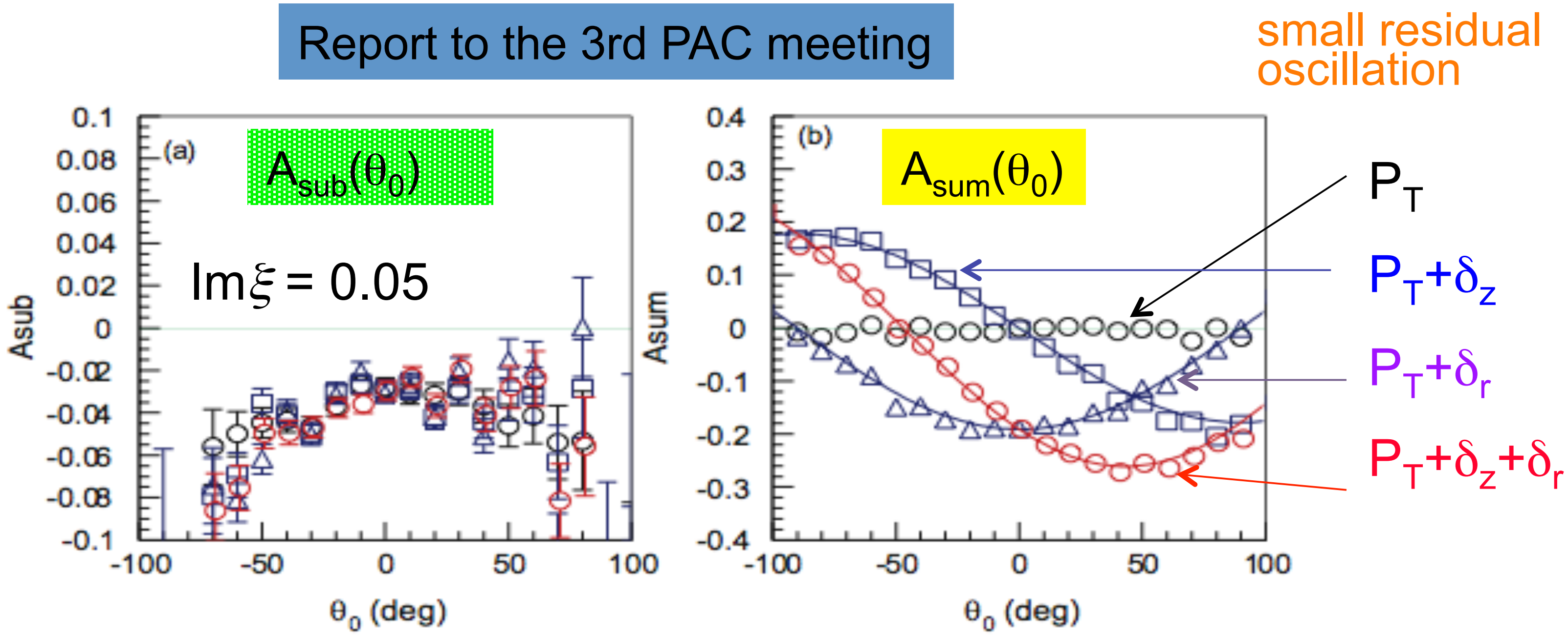
Misalignment analysis using $K_{\mu 3}$

Asymmetry analysis in terms of θ_0 : in-plane muon spin angle from z-axis

$$A_{sum}(\theta_0) = (\bar{A}_{fwd}(\theta_0) + \bar{A}_{bwd}(\theta_0)/2 = \alpha_0\{\delta_r\cos\theta_0 - \delta_z\sin\theta_0 + \boxed{\eta(\theta_0)}\} + \gamma$$

$$A_{sub}(\theta_0) = (\bar{A}_{fwd}(\theta_0) - \bar{A}_{bwd}(\theta_0))/2 = F(P_T, \theta_0).$$

Report to the 3rd PAC meeting

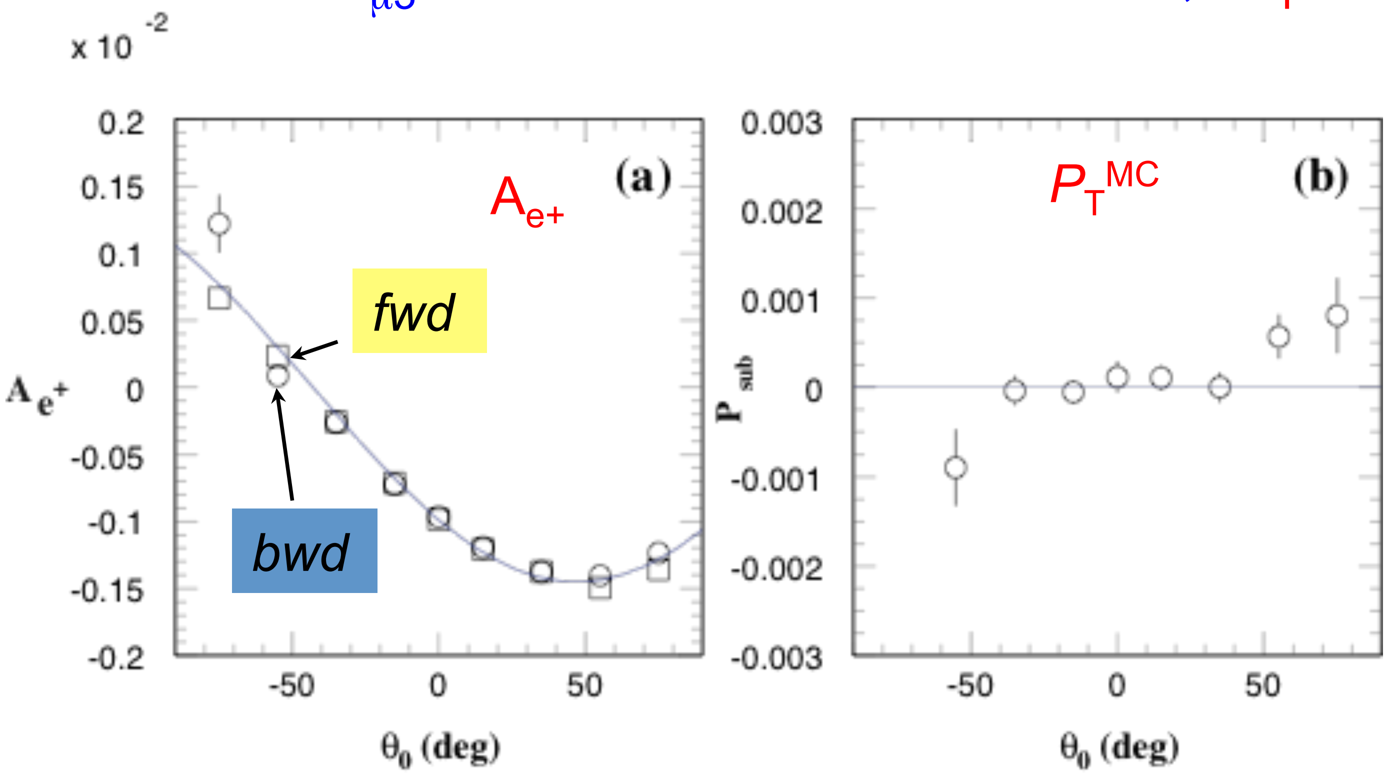


- $\Delta\delta_z \sim \Delta\delta_r \sim 3 \times 10^{-4}$ for misalignment determination
- $P_T = 0$ and $\delta_z = \delta_r = 5^o = 87$ mr (for systematic error test)

==> $\delta P_T = (2 \pm 7) \times 10^{-4}$ for 10^8 events

High statistics MC simulation

250×10^8 $K_{\mu 3}$ events with $\delta z = \delta r = 10$ mr, $P_T = 0$



$P_T^{MC} = \langle P_{sub} \rangle = (3 \pm 6) \times 10^{-5}$

- Within the statistical error, no bias was found in the analysis of this MC data nor the analysis code itself.
- Final systematics check will be done using the final analysis code together with a detailed analysis of real data.

Physics of P36: Lepton universality violation and heavy neutrino search

Lepton universality in $K_{\ell 2}$ and $\pi_{\ell 2}$ decays

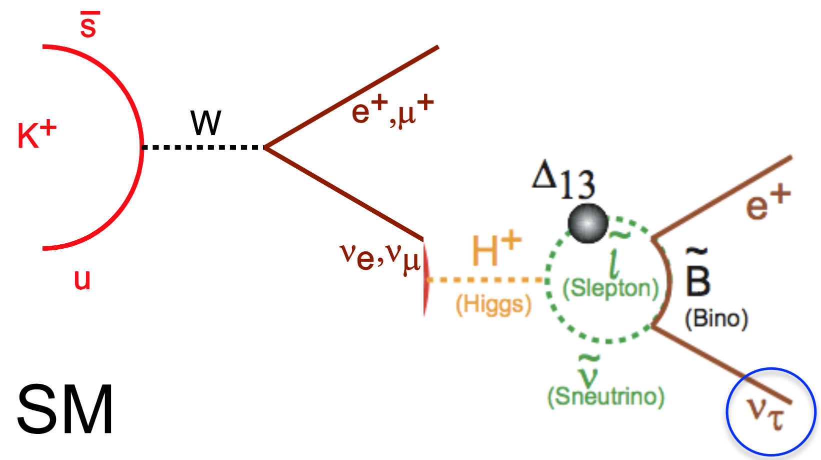
$$\boxed{R_K^{SM} = \frac{\Gamma(K^+ \to e^+\nu)}{\Gamma(K^+ \to \mu^+\nu)} = \frac{m_e^2}{m_\mu^2}\left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 (1+\delta_r)}$$

- Very precise SM predictions

$R_K^{SM} = (\ \ 2.477 \pm 0.001) \times 10^{-5}$

$R_\pi^{SM} = (12.352 \pm 0.001) \times 10^{-5}$

[V. Cirigliano and I. Rosell, Phys. Rev. Lett. 99 (2007) 231801]



- High sensitivity to LFV beyond SM

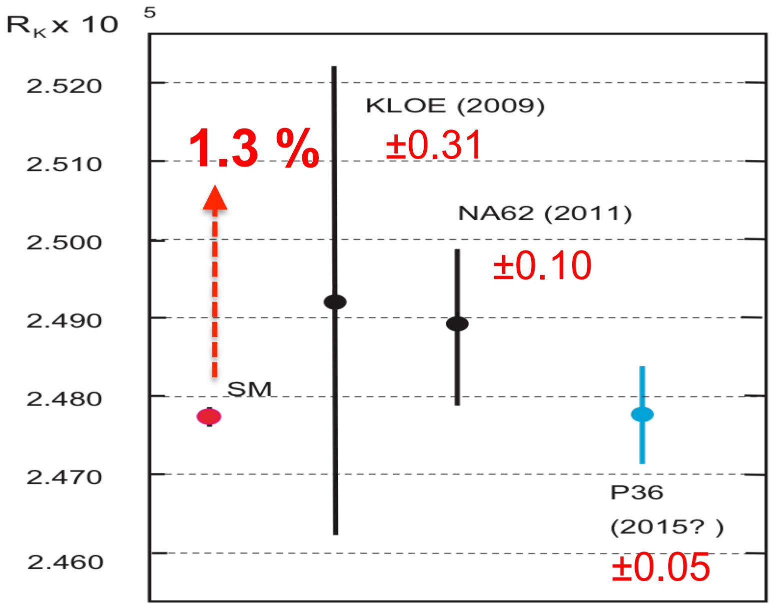
[Masiero, Paradisi and Petronzio, Phys. Rev. D74 (2006) 011701]

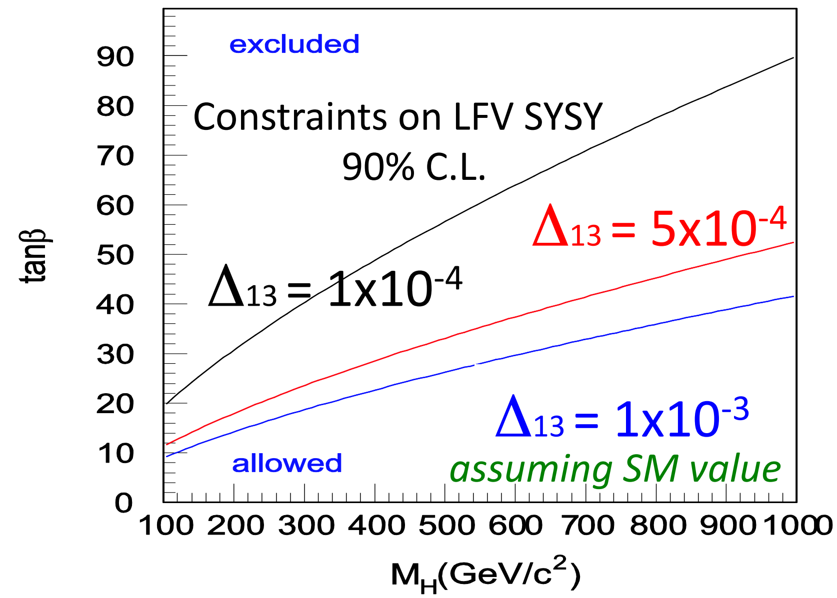
e.g. MSSM with charged-Higgs SUSY-LFV ⟹ $R_K^{LFV} \sim R_K^{SM}(1 + 0.013)$

$$R_K^{LFV} = R_K^{SM}\left(1 + \frac{m_K^4}{M_{H^+}^4} \cdot \frac{m_\tau^2}{m_e^2} \Delta_{13}^2 \tan^6\beta\right)$$

Expected Exp'tal precision ~ 0.2%, presentation to PAC11

Impact of P36-LFU





New Pseudoscalar Interaction

$$R_K^P \sim R_K^{SM}\left[1 \pm \frac{\sqrt{2}\pi}{G}\frac{1}{\Lambda_{eP}^2}\frac{m_K^2}{m_e(m_d+m_u)}\right]$$

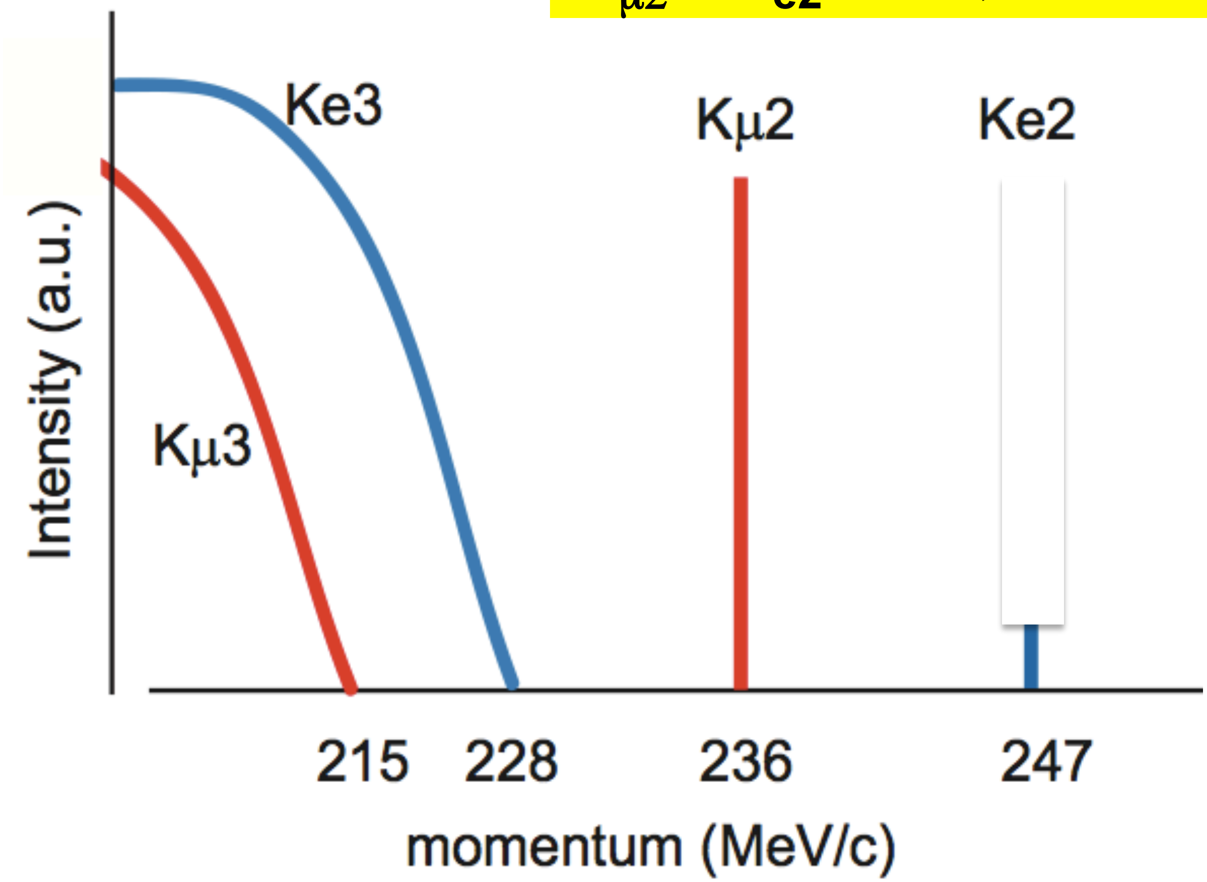
$$\frac{R_K^P}{R_K^{SM}} \sim 1 + \left(\frac{1\text{TeV}}{\Lambda_{eP}}\right)^2 \times 10^3,$$

$\Delta R_K/R_K = 0.2\%$

$\Lambda_{eP} \sim 750$ TeV

Experimental Challenges

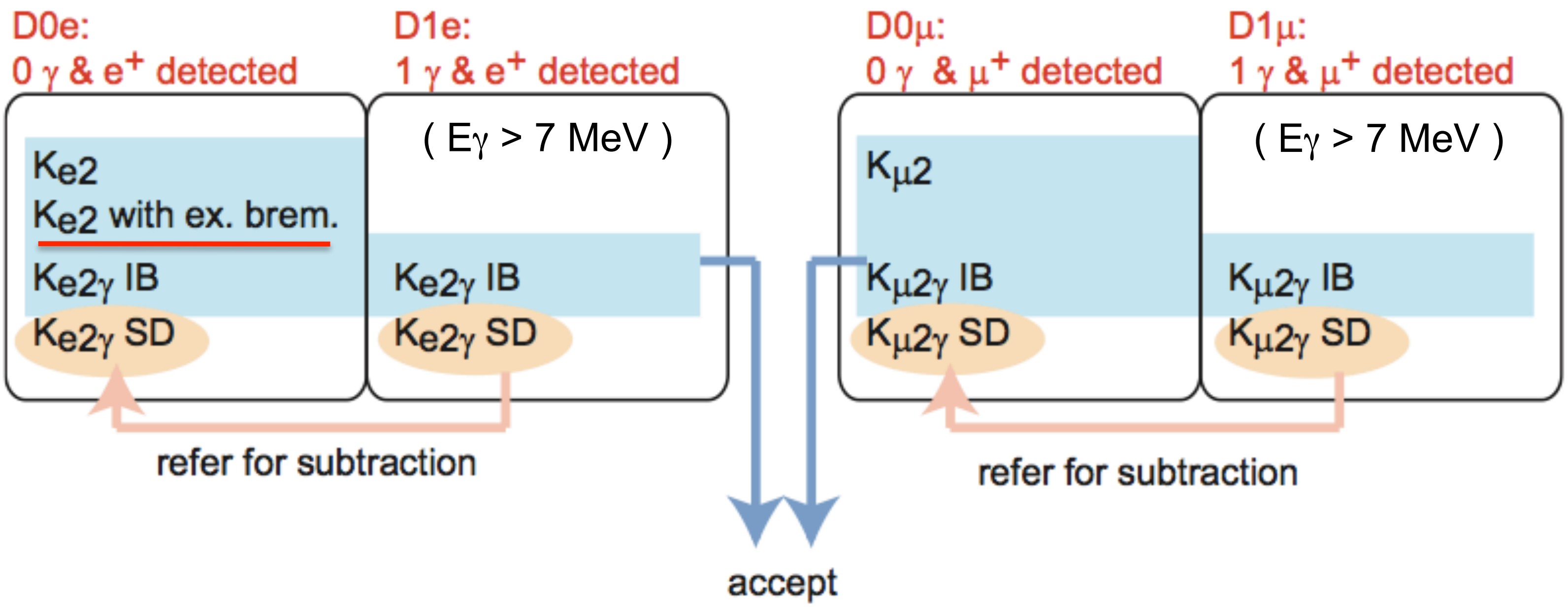
$N_{\mu 2} / N_{e2} \sim 40{,}000 / 1$



$\sigma_p \sim 1$ MeV/c

$\sigma_t \sim 100$ psec

Proposed Experimental Method



SD Bkgd
in D0 events
--use MC

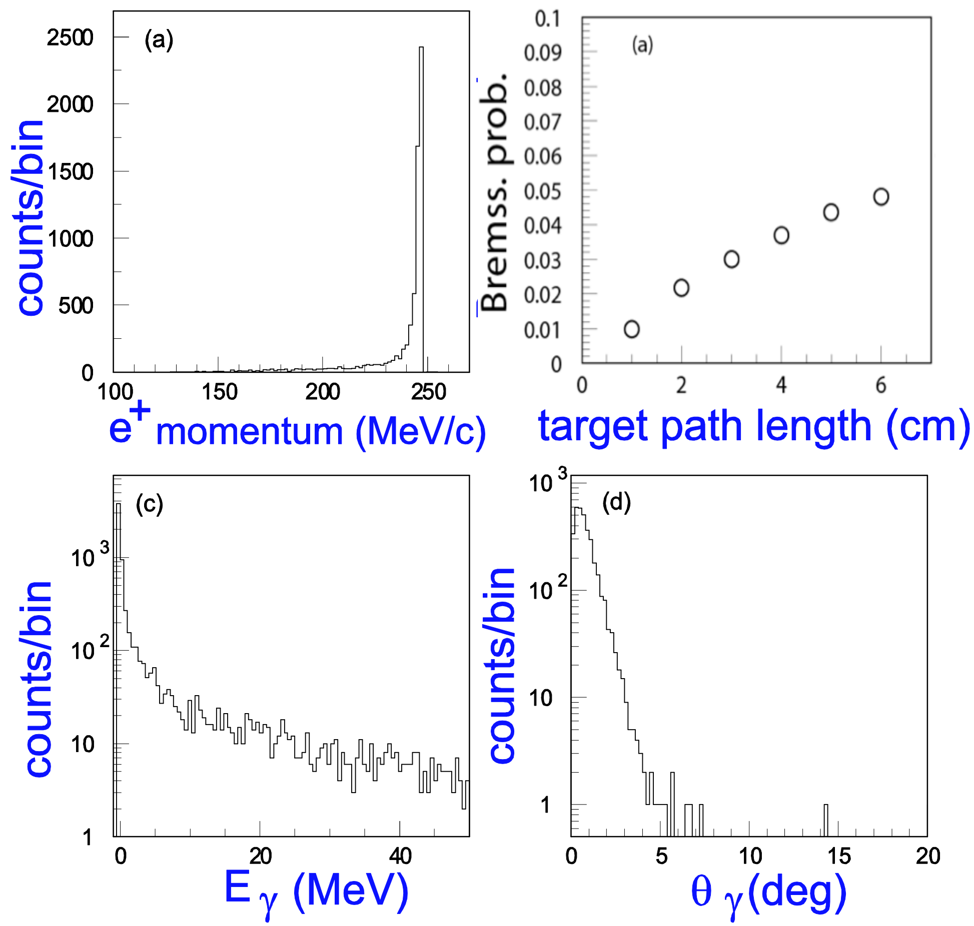
$$\frac{N(K_{e2}^{SD},0\gamma)}{N(K_{e2})} = \frac{BR(K_{e2}^{SD})}{BR(K_{e2})} \cdot \frac{\Omega(K_{e2}^{SD},0\gamma)}{\Omega(K_{e2})}$$
$$= \frac{1.52 \times 10^{-5}}{1.55 \times 10^{-5}} \cdot \frac{0.513 \times 10^{-2}}{6.99 \times 10^{-2}} = 0.072,$$

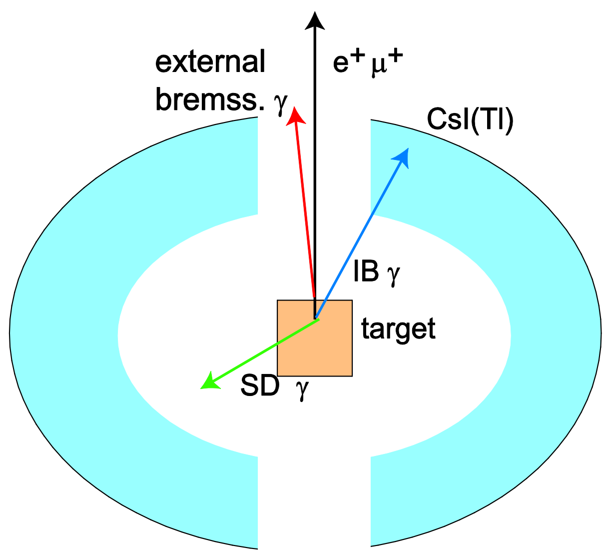
MC – External Brems spectra

(1) K_{e2} including external bremsstrahlung photon (in target)

(2) $K_{\mu 2}$

(3) Radiative K_{l2} decays



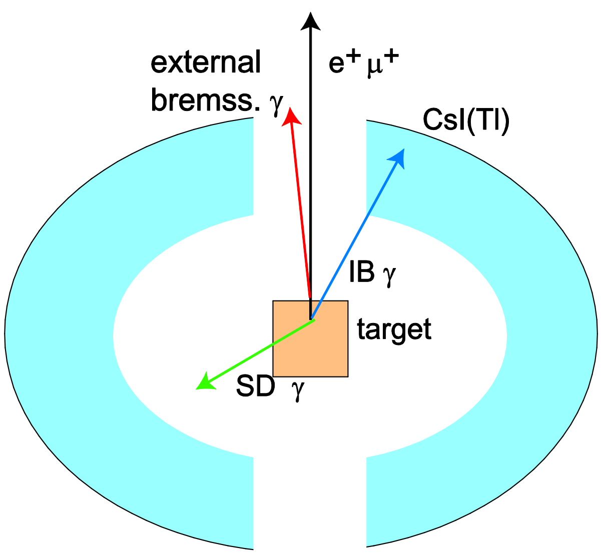


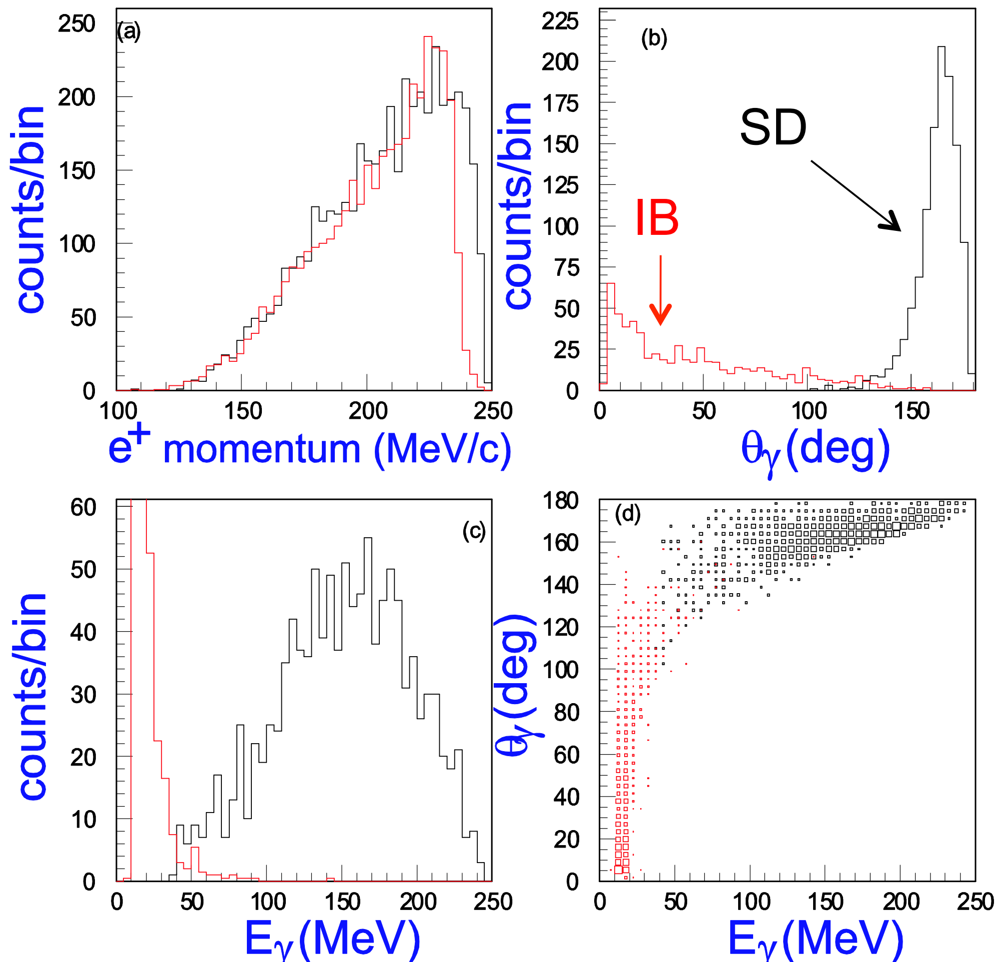
Subtraction of SD γ Bkgd

(1) K_{e2} including external bremsstrahlung photon (in target)

(2) $K_{\mu 2}$

(3) Radiative K_{l2} decays





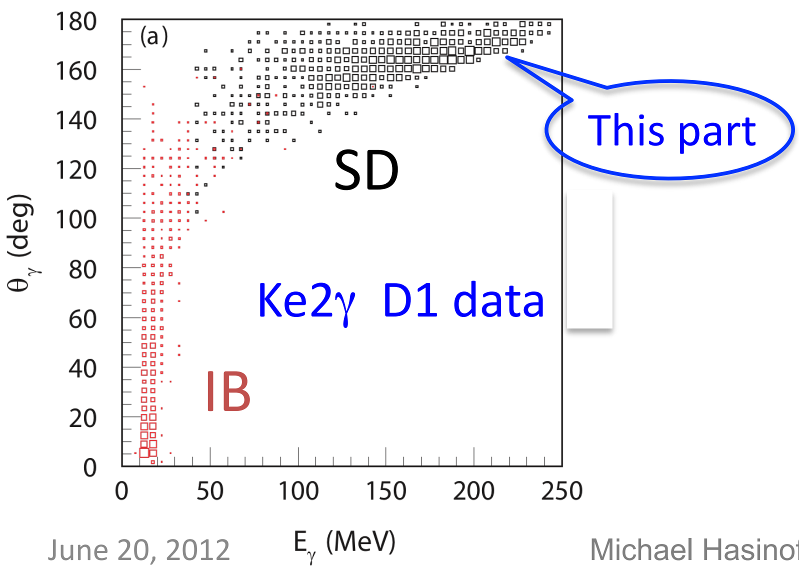
Black: Structure dependent
Red: Internal bremsstrahlung

IB and SD – well separated

$\delta R_K/R_K$ (SD) < 0.04%

SD subtraction - CsI(Tl) efficiency

- Photon detection uncertainty arises from:
  - Effective solid angle dependence on $\rho(K^+)$
  - Instability of detection threshold E_{th}
  - Clustering efficiency dependence on event rate
- Main effect in P36 is the detection efficiency of $K_{e2\gamma}$ (SD dominated), which is used for the D0-SD subtraction. Other effects are relatively harmless.



$\delta R_K / R_K = 0.0007$

- ➢ Necessity of gain monitoring
- ➢ Event rate stability required

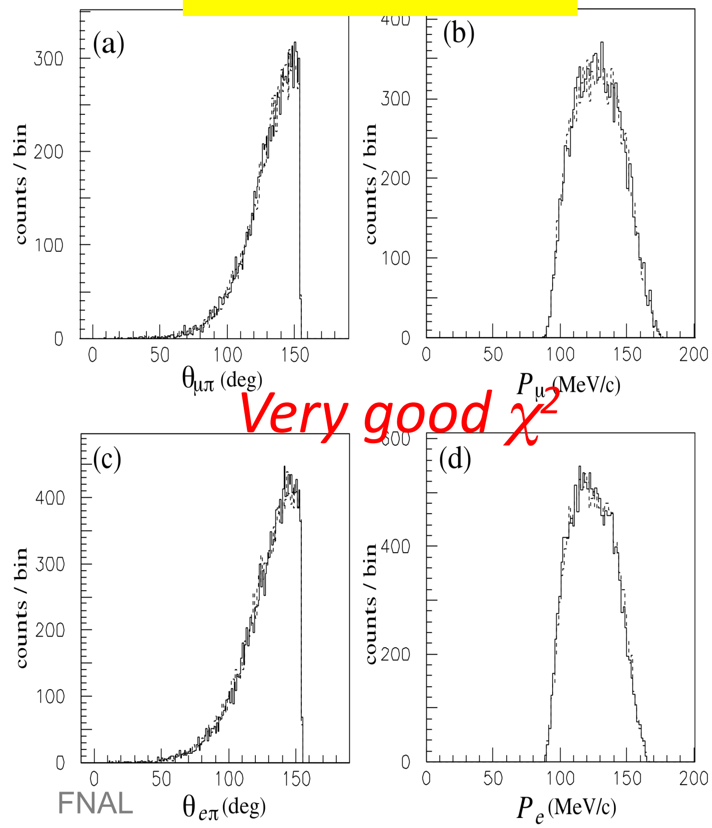
Acceptance – Using MC simulation

$$Q = \frac{N_{MC}^{accpt}(K_{e2} : B = 1.4\mathrm{T})}{N_{K_{e2}}^{decay}} \Big/ \frac{N_{MC}^{accpt}(K_{\mu 2} : B = 1.4\mathrm{T})}{N_{K_{\mu 2}}^{decay}}$$

- Use MC code from E246
- Precise geometry input needed
- Physics input -- K^+ distribution
- 100 times more events in P36

- However, the result must be checked using real data

Fit to E246 data



Very good χ^2

Acceptance – Using $K_{\mu 2}$ peak

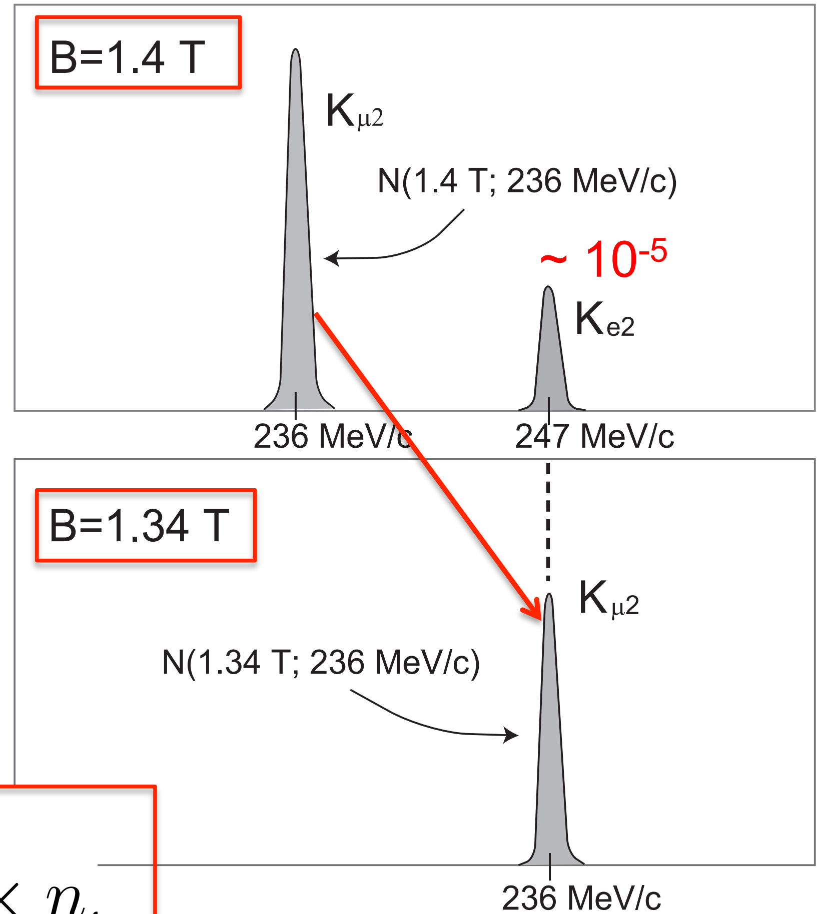
- Calibration run with reduced field to realize the same trajectory

  (shift the position of the $K_{\mu 2}$ peak)

  – *n* : beam normalization between the two runs

  – β : magnetic field effect

➢ Precise B field calculation and tracking simulation are needed



$$\boxed{Q = \frac{N(K_{\mu 2}; \mathrm{B} = 1.34\ \mathrm{T})}{N(K_{\mu 2}; \mathrm{B} = 1.4\ \mathrm{T})} \times \beta \times n,}$$

➢ Error arises from the uncertainty of corrections, *n* and β

Acceptance – Using $K_{\mu 3}$ spectrum

- Use of wide *p* spectrum
- Calibration run with

  reduced B field of 0.9 T

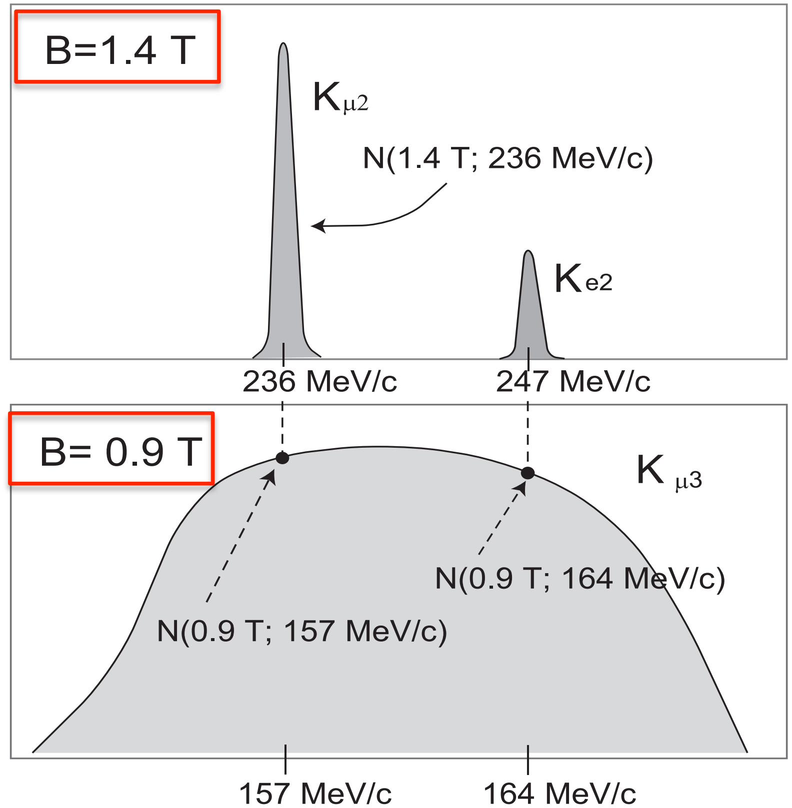
  164 MeV/c : 247 MeV/c K_{e2}

  157 MeV/c : 236 MeV/c $K_{\mu 2}$

α : spectral ratio

β' : magnetic field effect

γ : CsI(Tl) efficiency effect

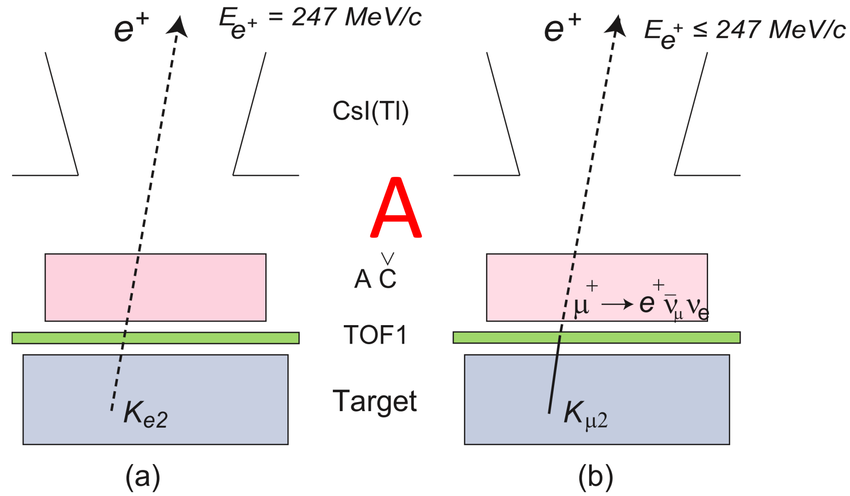


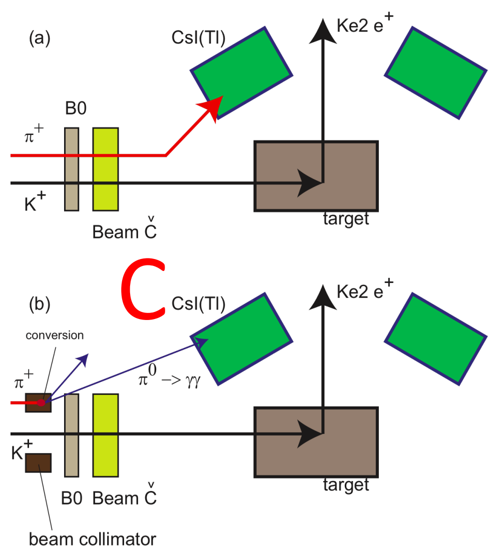
$$Q = \frac{N(K_{\mu 3}; B = 0.9\ \mathrm{T}; 164\ \mathrm{MeV}/c)}{N(K_{\mu 3}; B = 0.9\ \mathrm{T}; 157\ \mathrm{MeV}/c)} \times \alpha \times \beta' \times \gamma.$$

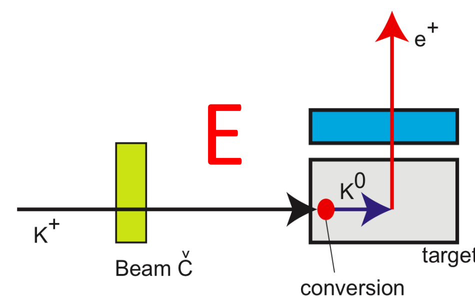
- ➢ One calibration run -- no necessity for beam normalization
- ➢ More promising method

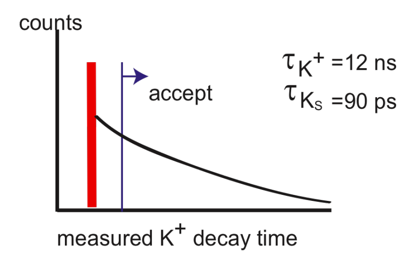
Backgrounds

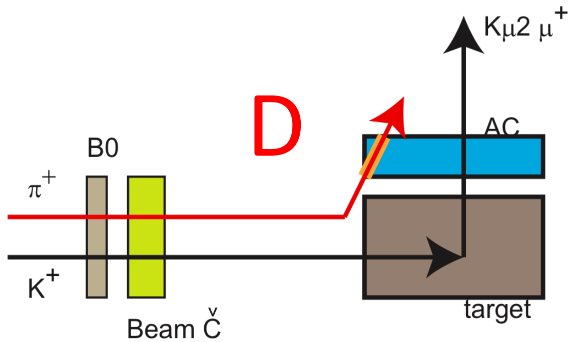
- Physics backgrounds
  - A. In-flight μ^+ decay
  - B. Photon conversion
- Beam origin accidentals
  - C. Beam hit in CsI(Tl)
  - D. Beam hit in AC
  - *E.* K^+ to K^0 conversion
  - *F.* K^+ in-flight decay











- $\delta R_K/R_K$ in "Summary Table"

Summary of systematic errors

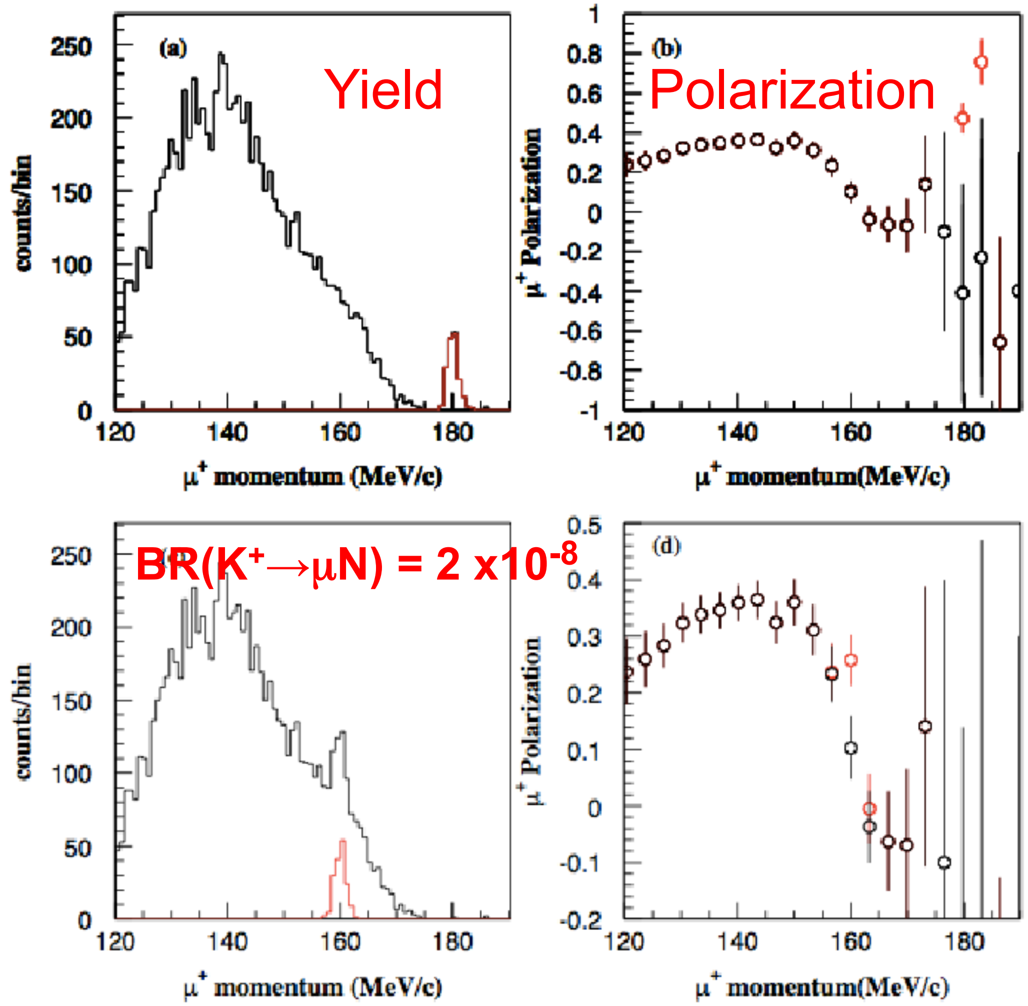
Error source	$\Delta R_K/R_K$	Comment
(1) **Detector performance**		
Chamber efficiency	0.0004	Method-1
PID performance	0.00035	$K_{e2}/K_{\mu 2}$ run
2 → CsI(Tl) performance	0.0007	Ambiguity of efficiency
Trigger and DAQ	small	to be measured
(2) **Background**		
Muon decay in flight	0.00015	Distance to AC
Photon conversion	0.0002	
CsI(Tl) beam hit	0.00018	
AC beam hit	0.0001	
K^+ conversion	0.00003	
(3) **Analysis**		
Code and cut parameters	small	$\ll 0.001$
SD subtraction	0.00036	
(4) **MC simulation**		
1 → Acceptance ratio	0.00078	based on E246
Magnetic field	small	< 0.0001
Input parameters	small	$\ll 0.0001$
Kaon stopping distribution	0.00015	
Target interactions	0.0004	
Material thickness	0.0002	
IB theory	small	$\ll 0.001$
Total	0.0015	

+ 4 other items
at ~ 0.00040

$\delta R_K/R_K$(syst) = 0.0015 while $\delta R_K/R_K$ (stat) = 0.0020

Search for heavy sterile ν in $K^+ \rightarrow \mu^+ N$

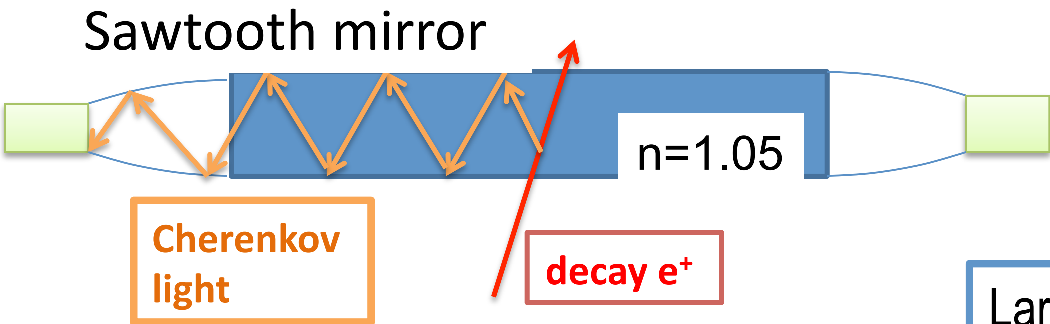
- **In the framework of renormalizable extensions of the SM, eg. the νMSM, 3 light singlet right-handed (sterile ν) are introduced**
- **The νMSM can explain**
  - **ν oscillation**
  - **Light sterile ν play a role in Dark matter**
  - **Baryon asymmetry can be induced by leptogenesis or through ν oscillation**
- **Measure yield and polarization for $K^+ \rightarrow \mu^+ N$**
  - **Main background from $K_{\mu3}$**



Detector R&D and construction

R&D -- Aerogel Cherenkov Counter

For e^+/μ^+ discrimination



- **1st Prototype counter**

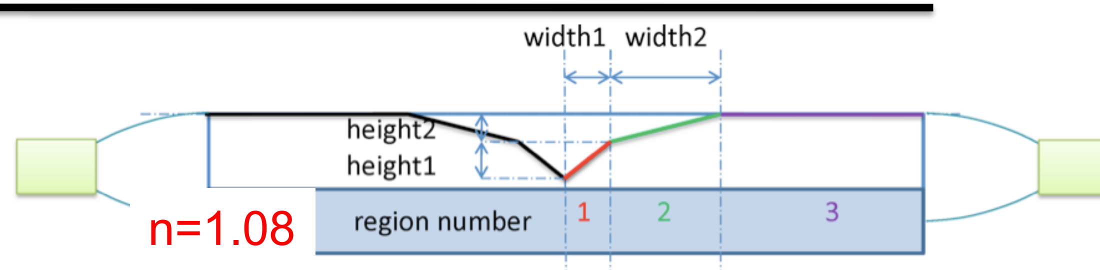
Large light loss due to:
- Rayleigh Scattering inside aerogel
- Long thin detector -- reflection loss

Beam test

Large angle incidence -- efficiency as high as 99.9 … but
Small angle incidence -- efficiecy is as low as 80 %

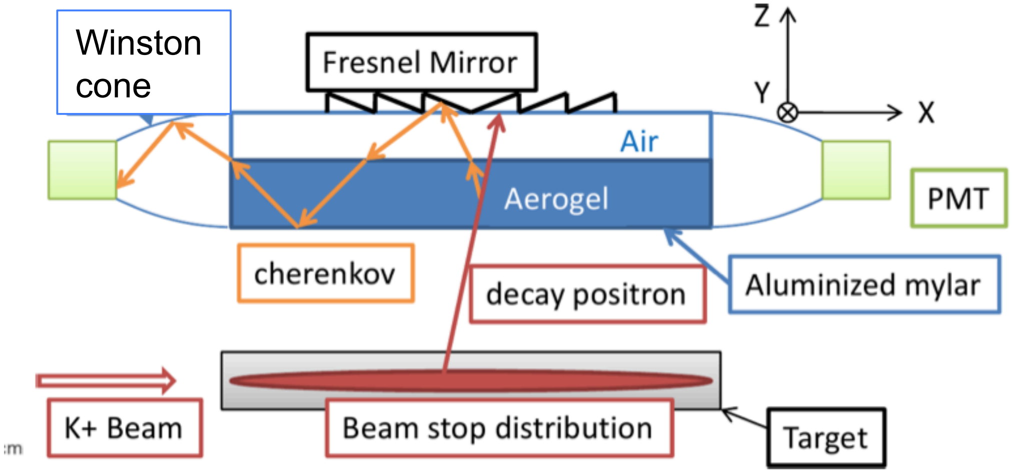
- **2nd Prototype counter**

– variable mirror



- Simulation code has been updated and reproduces the 1st prototype test result
- Mirror shape, aerogel shape, PMT are all optimized by this MC simulation
- Total efficiency is now estimated to be as high as 99.6 ± 0.03 % even for small angles
- Second prototype counter is currently being tested at J-PARC

R&D – Aerogel Č Counter Reflectors

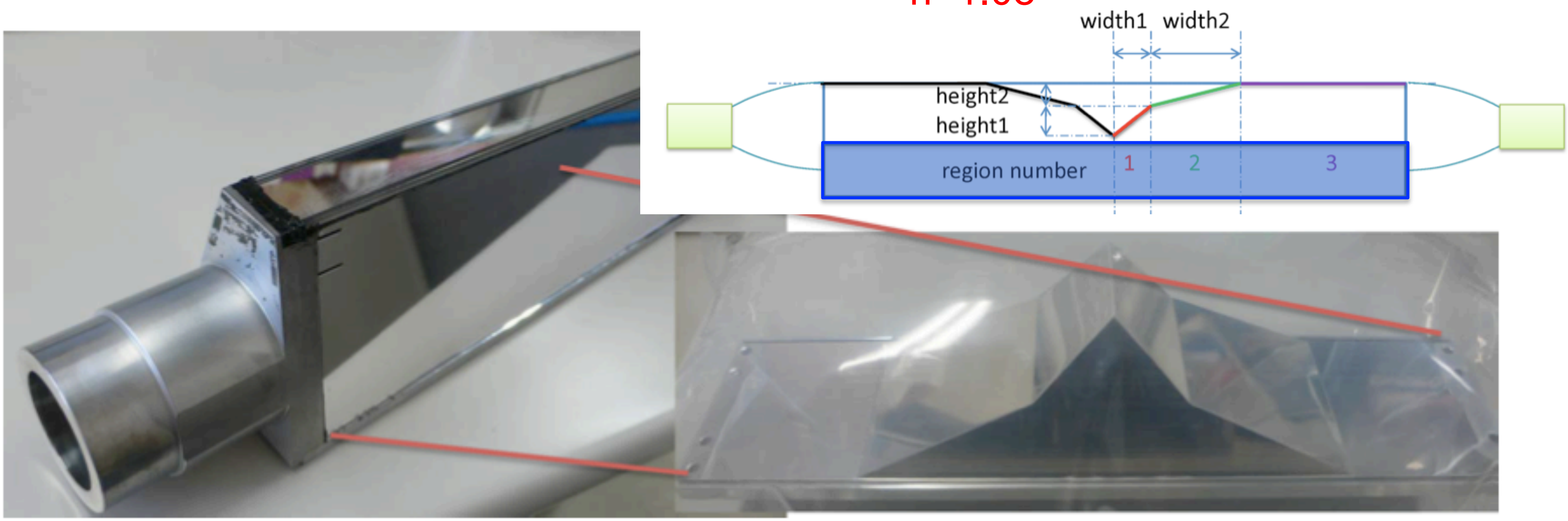


1st prototype – sawtooth mirror

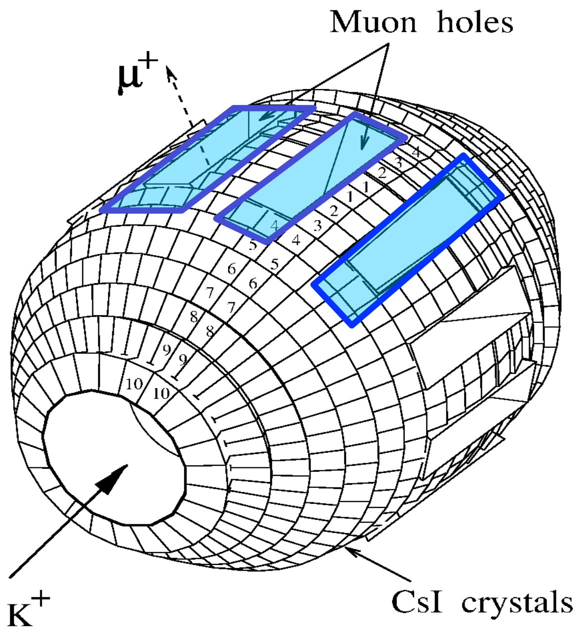
n=1.05

2nd prototype – variable mirror

n=1.08

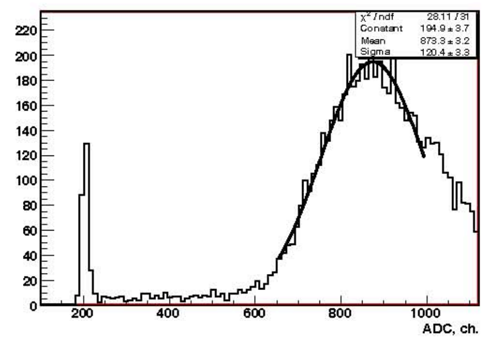


R&D -- APD Readout for CsI(TI)

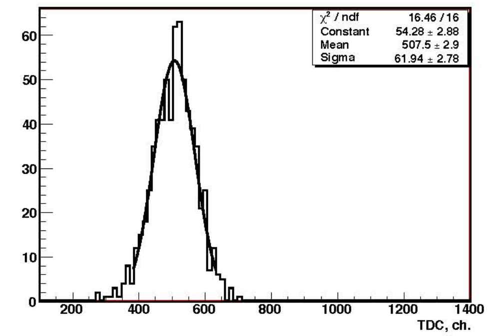


- Improve the timing characteristics of CsI(TI) by replacing PIN diode with APD
- Pulse shaping and pile-up analysis

One-module energy



One-module timing



Parameter	E06 APD readout	E246 PIN readout
Electron yield	47,000/MeV	11,000/MeV
Noise level	not yet measured	70 keV
Energy resolution	~12% for C.R.	12% for C.R.
Time rsolution	3 ns for C.R.	12 ns for C.R. (9 ns for all)
Pulse width	$\sim 1.5\ \mu s$	$15\ \mu s$
Rate performance	~ 500 kHz	34 kHz

only needed for E06 new requirement too slow

ISC, Kharkov, Ukraine

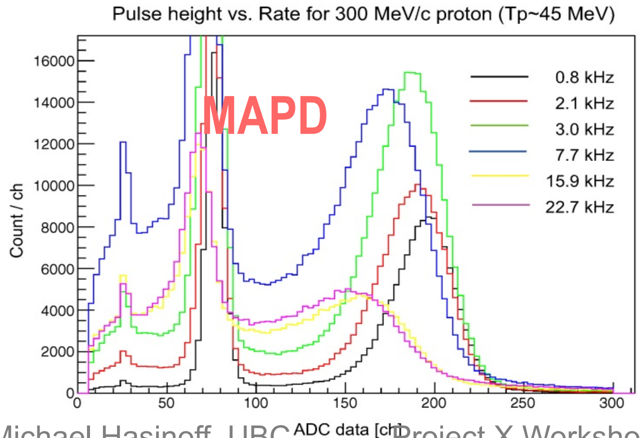
Yuri Kudenko, INR, Moscow

- Both 1 and 9 module tests have been performed using an e^+ beam at Tohoku Univ. to check the energy resolution and high-rate performance of APD readout

R&D -- APD Readout for CsI(Tl)

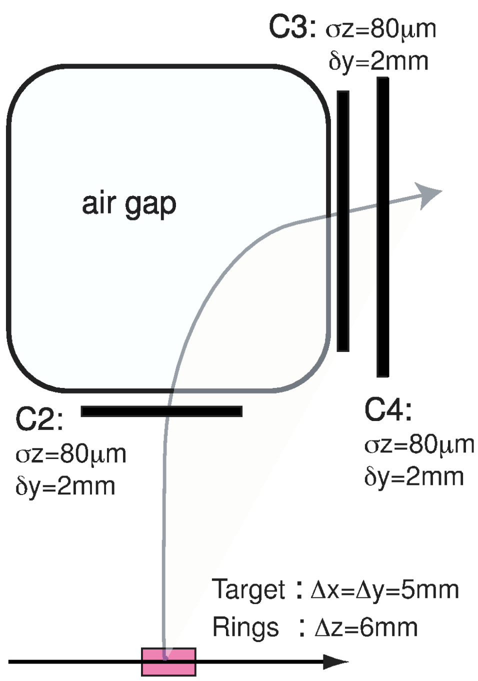
For higher rate performance

- Possible 3 candidate schemes:
  - PIN-diode readout (same as in E246)
    - Best K/π ratio is required (Beam line K1.1BR)
  - APD readout (developed in 2010) (Proportional 5 x 5 mm^2)
    - Already established, but expensive (Gain = 50 , 300 pe /MeV)
  - MAPD readout (development in progress now) (Geiger 3 x 3 mm^2)
    - Good S/N ratio, and cost effective (Gain = 10^5 , 70 pe /MeV)
    - Rate capability tested @ TRIUMF in Oct 2011

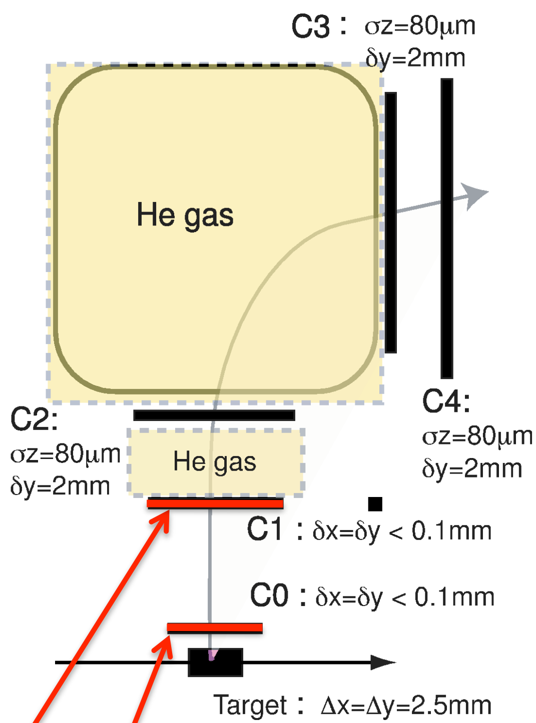


- *There is still some rate dependence*
- *Better MAPDs are under development*

TREK--LFU Tracking Upgrade

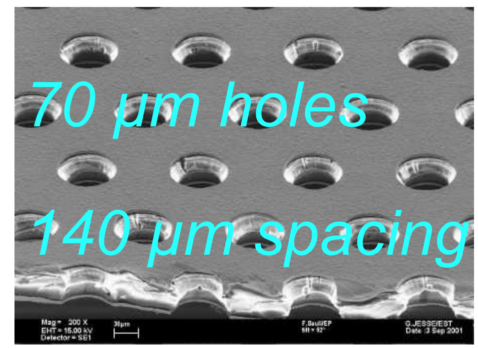


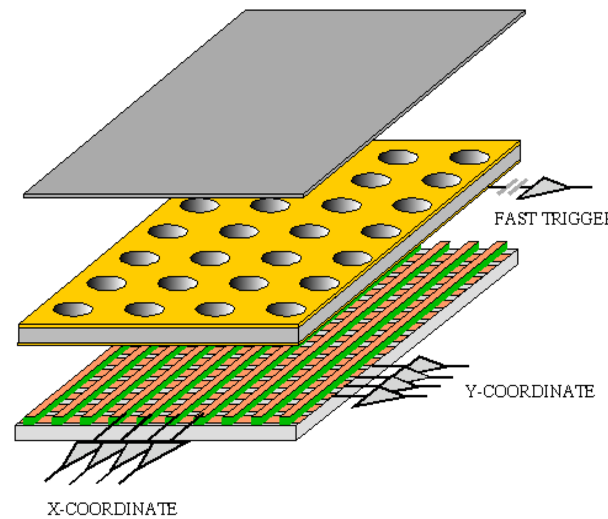
E246



J-PARC upgrade

GEM technology – Hampton University -- in collaboration with Jefferson Lab, & MIT



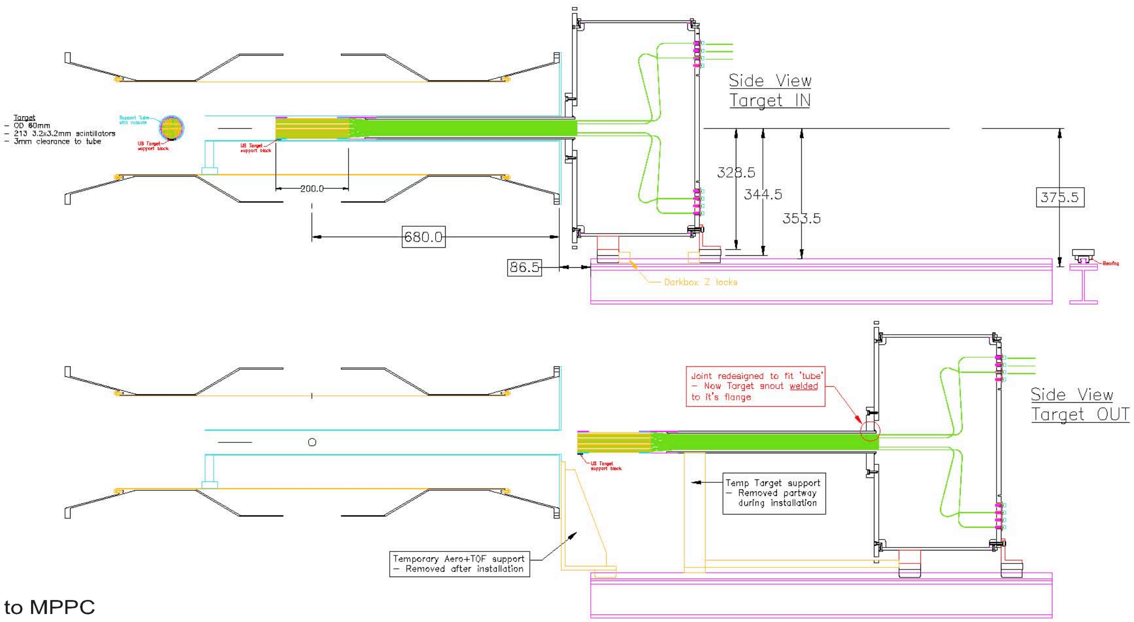


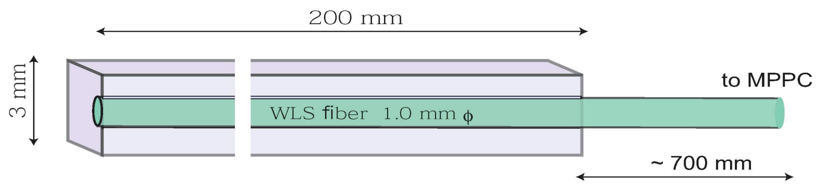
- **Planar GEMs (C1) between CsI and C2**
- **Cylindrical GEM (C0) as replacement for old C1 – for P_T**

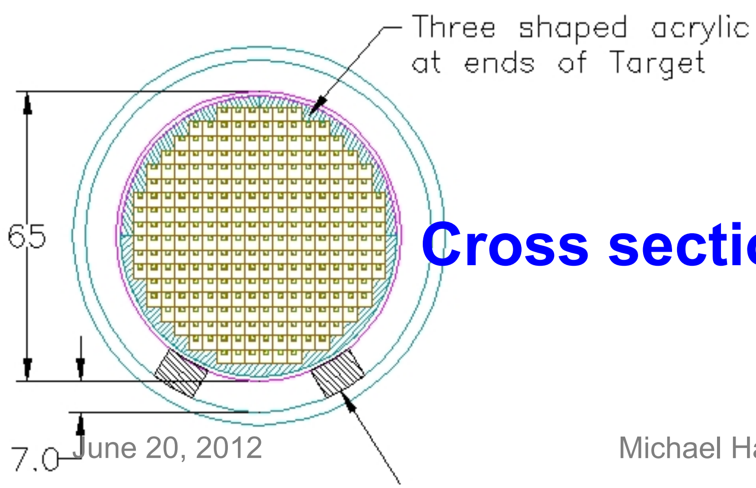
R&D – Sci Fibre Target for P36

For better tracking resolution

- 256 pieces of
- 3 x 3 x 200 mm^3 Scintillator
- WLS fibre L = 1.4m
- MPPC (SiPMT) readout
- EASIROC electronics
- Production in Canada



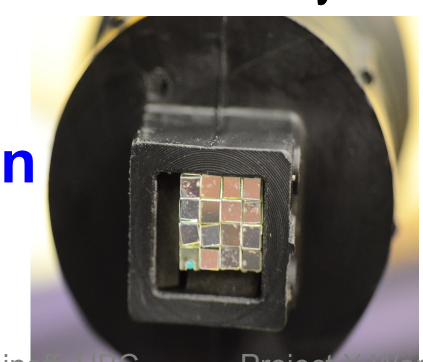


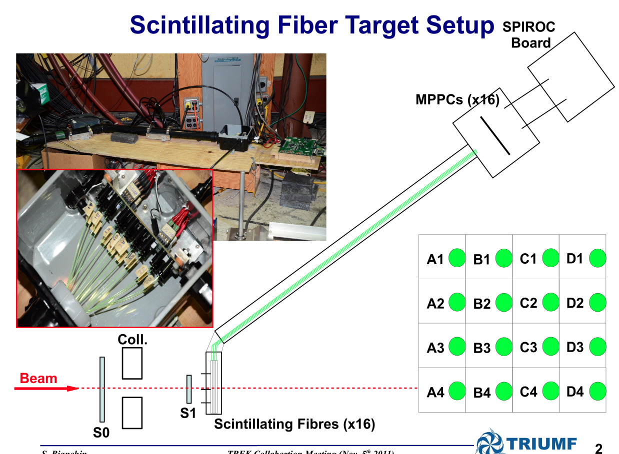


Cross section

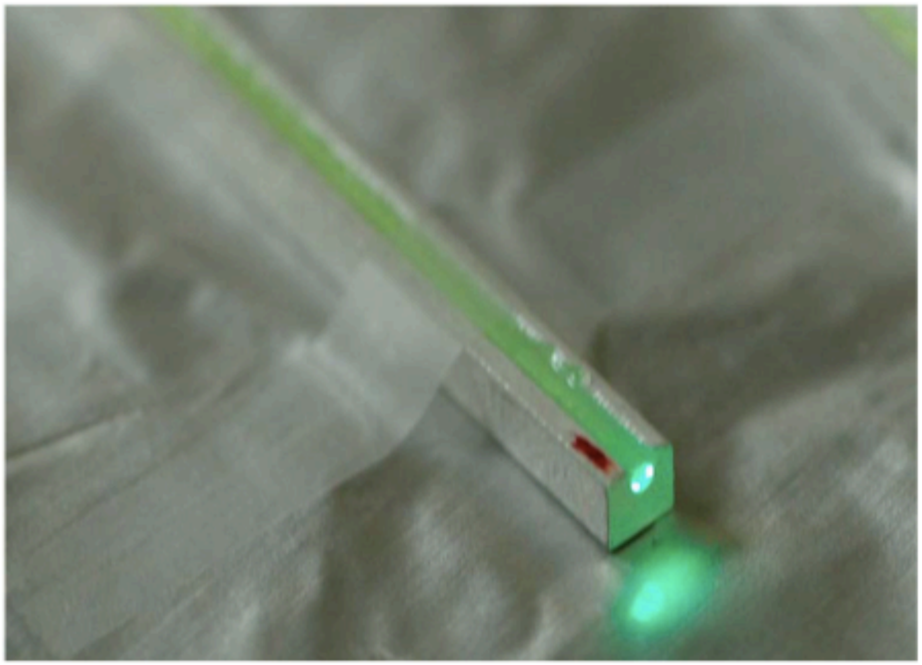
Beam test at TRIUMF in Nov 2011

4 x 4 array





Target Fibre & MPPC Couplers



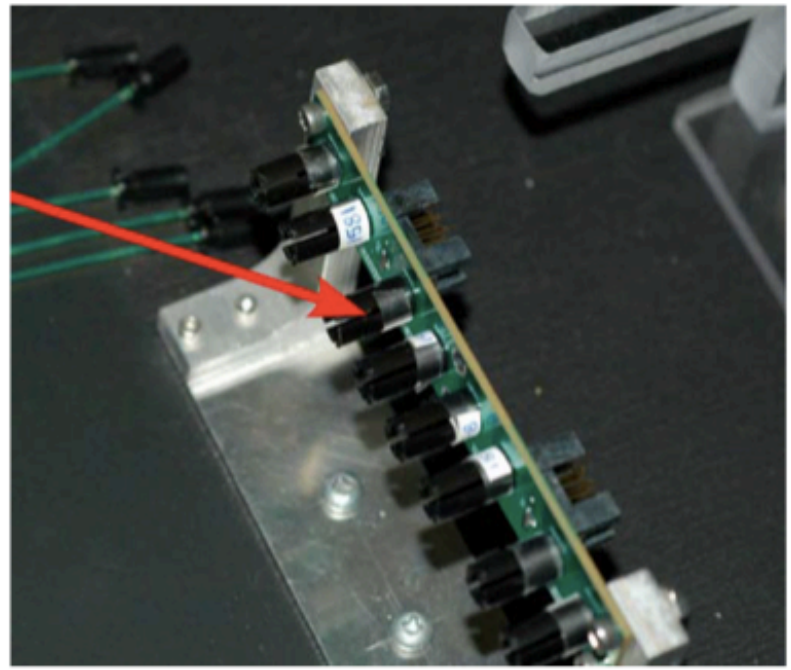
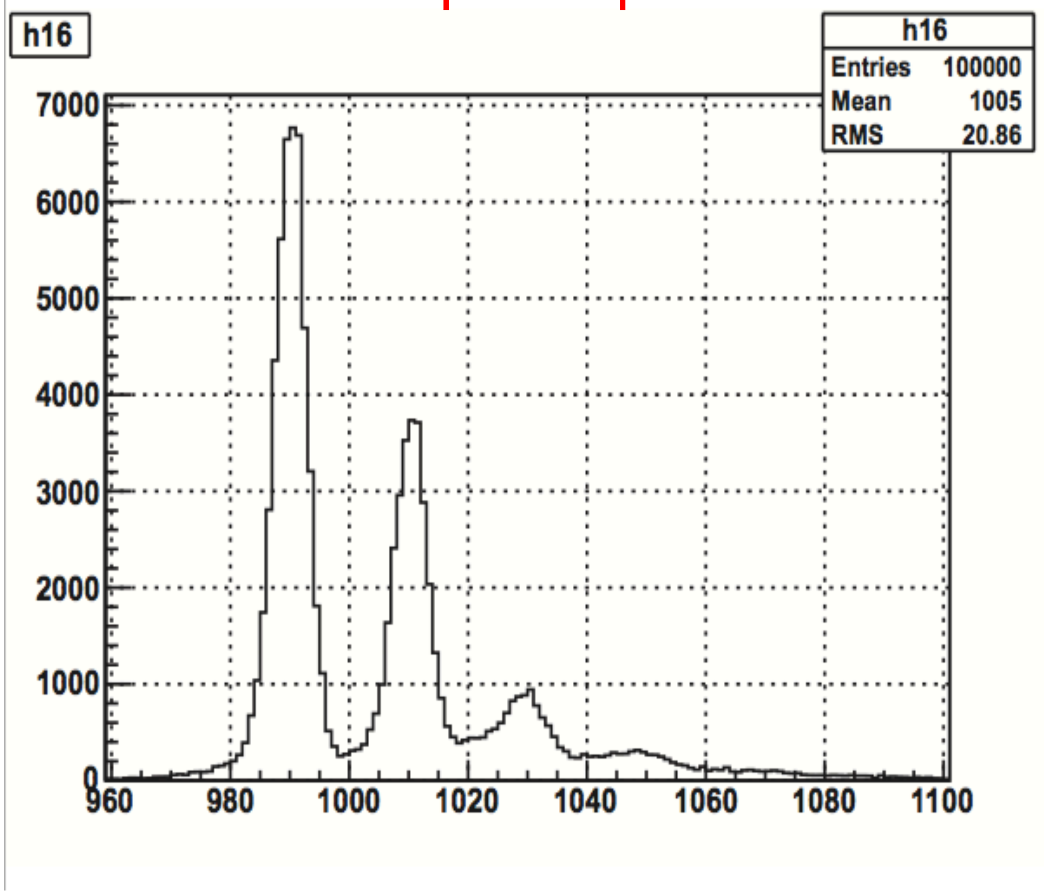


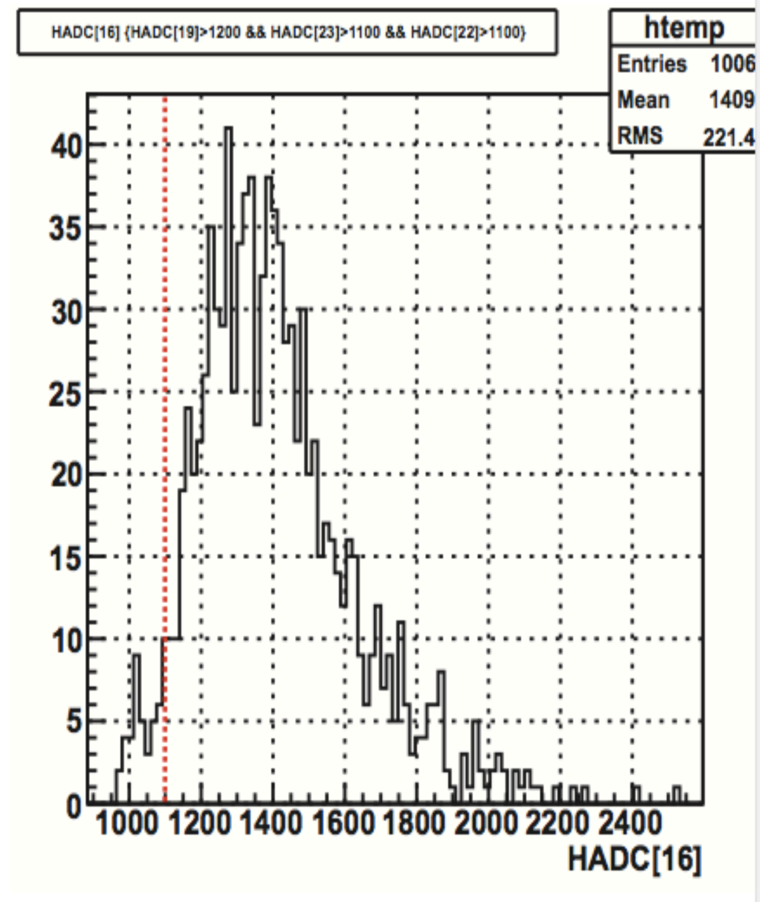
Fig 6/7. Green WLS fibre glued into a 3mm scintillating bar. Eight channel MPPC coupling board with the male coupler and female socket (which holds the MPPC).

MPPC Spectra

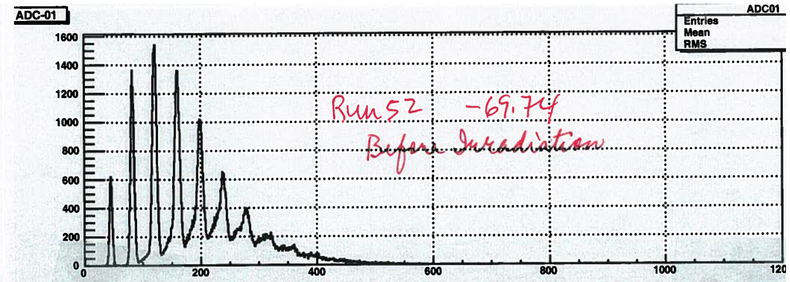
Noise Spectrum
Ped + 1 pe + 2pe

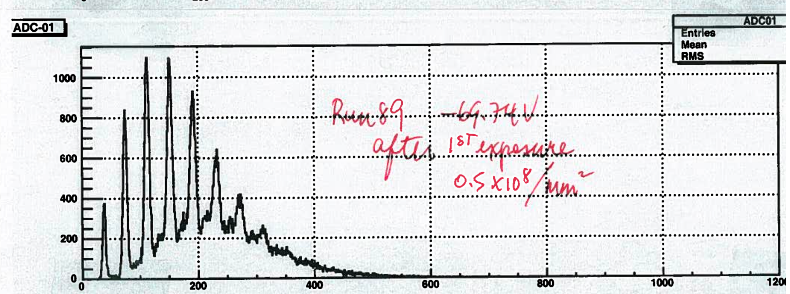


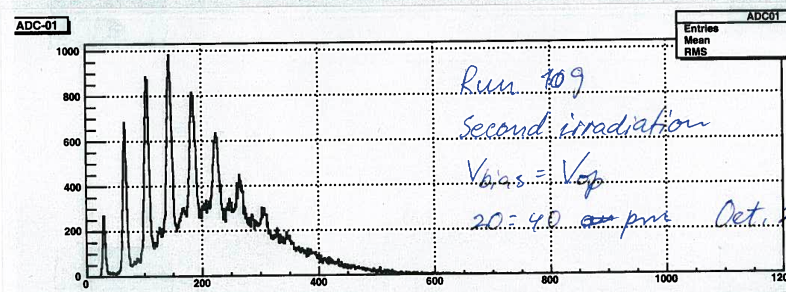
Cosmic Ray Spectrum
~ 30 pe/MeV

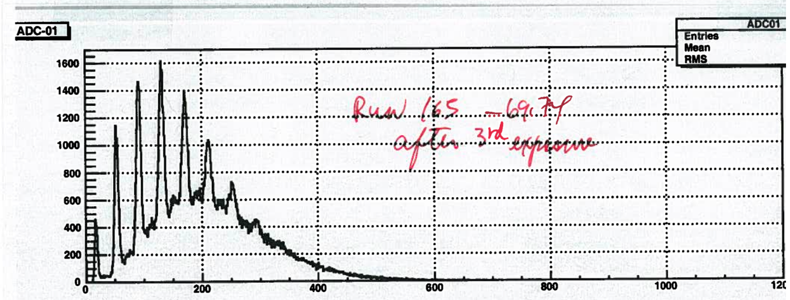


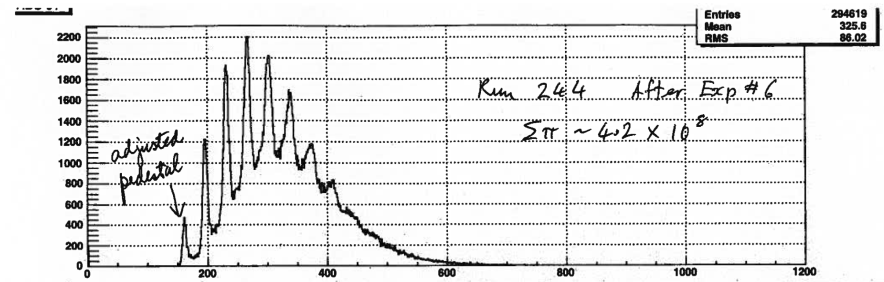
MPPC Rad Test with TRIUMF π^+ Beam

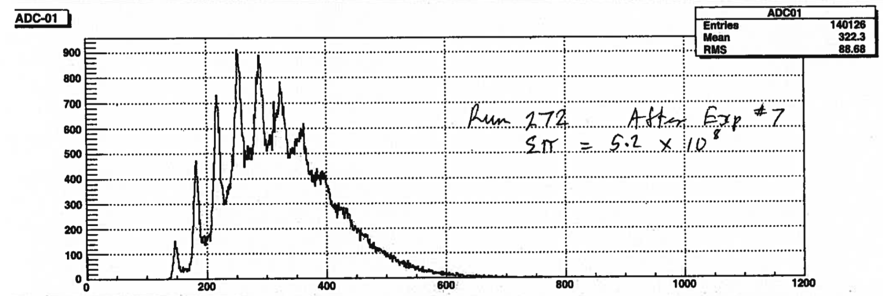


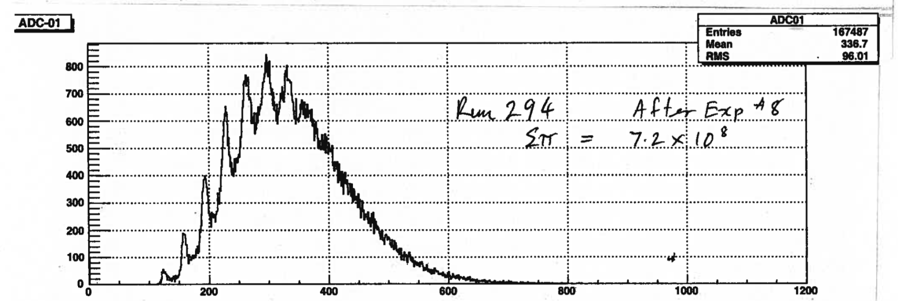


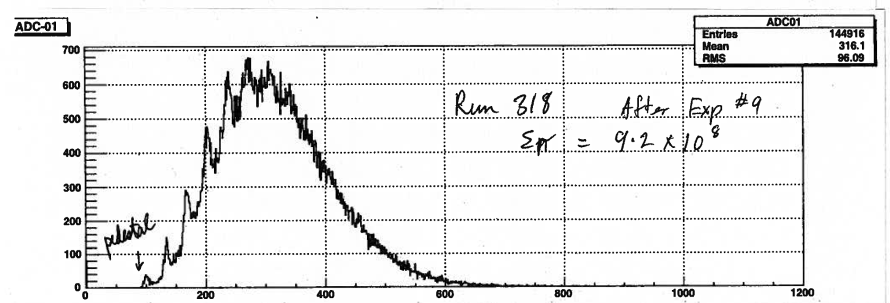












Upgrade Timeline

- **Target:**
  - **Finer segmentation of Target scintillating fibres Readout: MPPC (Si-PMT) Hamamatsu**
- **Particle ID:**
  - **Aerogel Cherenkov surrounding target, TOF**
- **Charged particle tracking:**
  - **Add new element C1 between CsI(TI) and C2**
  - **Add cylindrical GEM (C0) (remove aerogel)**
- **π^0 (1&2 photon) detection:**
  - **New, faster readout of CsI(TI): APD, MAPD**
  - **Wave form analysis using FADCs**
- **Muon polarimeter :**
  - **Active polarimeter with increased acceptance**
  - **New muon holding field magnet with a parallel field**

LFU
30 kW
~2014

TREK
270 kW
>100 kW
~201x

T. Koseki (KEK)--PAC13

SX power upgrade plan

	User operation	Accelerator study
2011.6-11(shutdown)	SX collimators	
2011.12-2012.6	3 - 5 kW	5 - 10 kW
2012.7-2012.9 (shutdown)	Ti chambers (SMS)	
2012.10-2013. 6	10 kW	50 kW
2013. 7-2014. 1 (shutdown)	Li 400MeV/50 mA, Ti chambers (ESS)	
2014. 2-2014. 6	50 kW	100 kW
2014.7 - 9(shutdown)		
2014. 10-	Toward 100 kW	

2011.12-2012.6: Recovery of the operation in the autumn 2010.
2012 summer: Installation of Ti chambers in the SMS section.
2013 summer: Installation of ESS with Ti chambers.

For duty
- Upgrade of RQ power supply for higher output voltage
- Coil short / ripple cancellor
- increase emittance
- ramping speed control of horizontal tune
- Replace the main magnet power supplies with newly developed ones (high rep. rate and low ripple)

T. Koseki (KEK)--PAC13

Improvements

Installation of additional shields of ring collimators:

Loss power capacity will be increased from 0.45 to 2 kW by installing additional shields and an absorber in the 2011 shutdown and an additional set of collimators in the 2012 shutdown.

Replacement of the injection kicker system:

The new kicker system has well shaping pulse, no extra kick and lower beam coupling impedance

Installation of 7^{th} and 8^{th} RF system:

Higher accelerating voltages and manipulation of longitudinal bunch form to reduce the effect of space charge force

Modification of the rf cooling water system

A separate cooling water system from the magnet system

Installation of solenoid coils on the rf excitor

Suppression of multipactoring for slow extraction with transverse rf

Installation of collimator system in the slow extraction straight section

Reduction of residual activation of the quadrupole magnet, which is located downstream of ESS.

T. Koseki (KEK)--PAC13

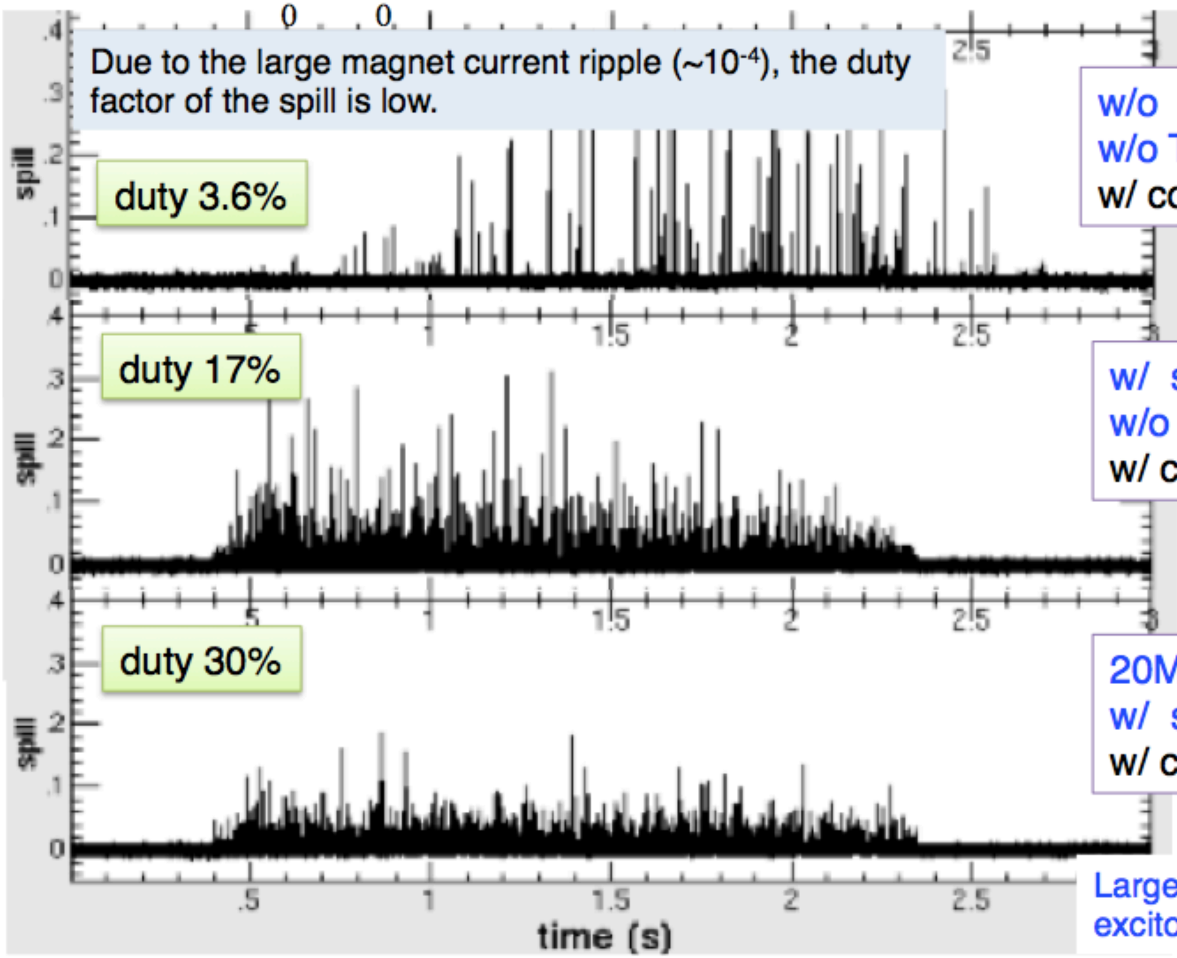
Time structure of the SX beam

$$Duty = \frac{\left(\int_0^T I dt\right)^2}{\int_0^T dt \int_0^T I^2 dt}$$

I(t): PM signal sampled at 100KHz through 10KHz LPF
t=0: spill start
t=T: spill length

Duty 100 %

RUN in Nov. 2010



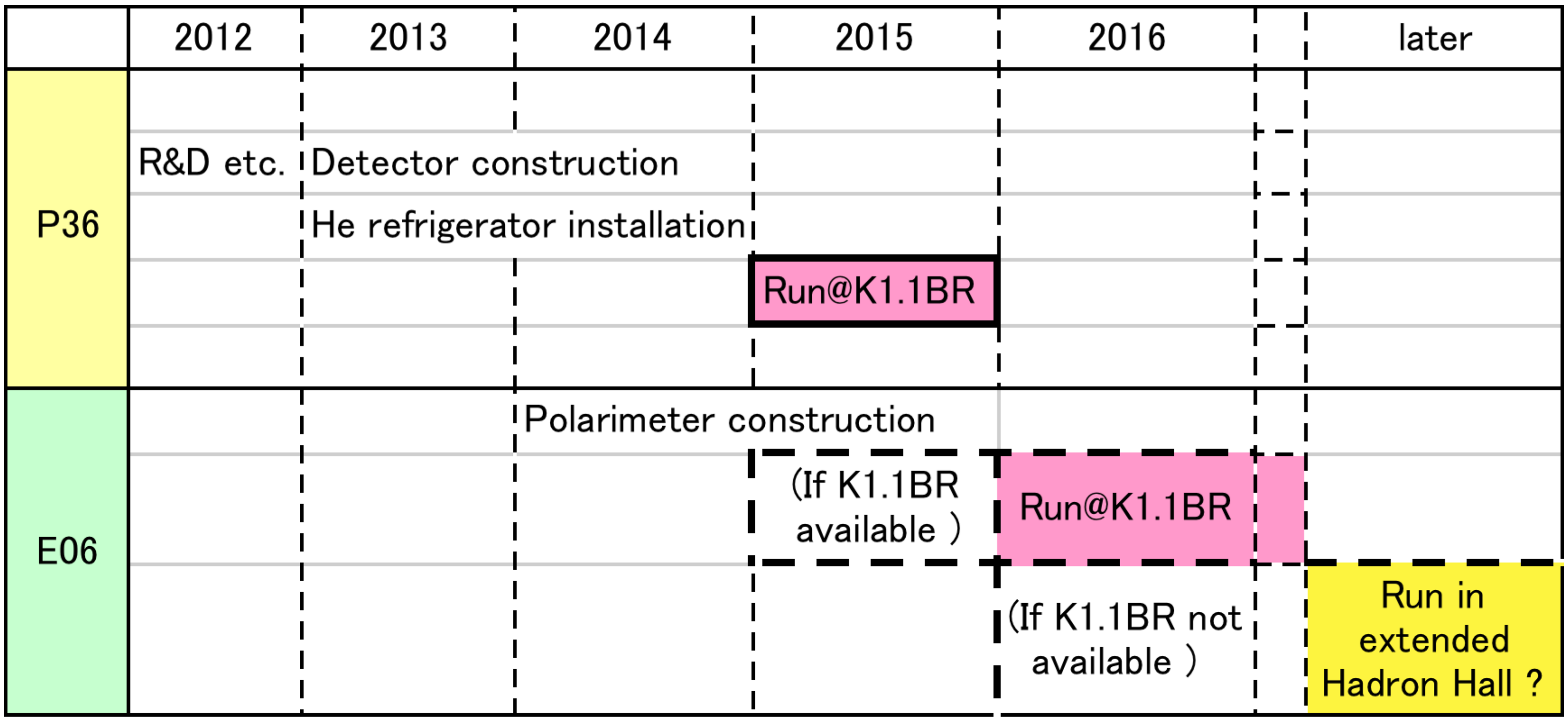
w/o spill FB,
w/o TRF
w/ coil short

w/ spill FB,
w/o TRF
w/ coil short

20MHz TRF ON, 5dBm,
w/ spill FB
w/ coil short

Large pressure rise occured in the excitor due to the multipactoring

Desired time schedule (TREK)

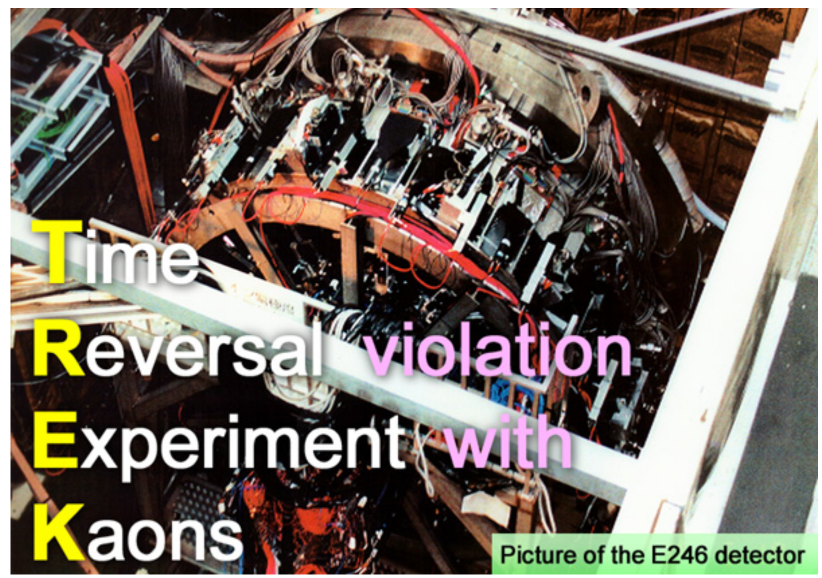


- We would like to run P36 at K1.1BR in 2015.
- If K1.1BR remains available, we want to begin E06 once the intensity reaches 250 kW; if K1.1BR is no longer available, we would like to run E06 in the Hadron Hall extension.

Summary

- **TREK at J-PARC is preparing two experiments**
- **"K1.1BR" secondary beamline has been commissioned**
- **$K_{e2}/K_{\mu 2}$ measurement to test lepton universality (2014-15) & a search for heavy sterile neutrinos**
  - **Use E-246 apparatus with partial upgrades**
- **Measurement of the T-violating transverse muon polarization in $K_{\mu 3}$ decay (~2016 ??)**
  - **Large potential for discovery of New Physics beyond the SM with a fully upgraded E-246 setup**

New collaborators are welcome!



Thank You

Merci

Arigato Gozaimasu

Spasibo

EXTRA SLIDES

Target interactions

Uncertainty of e^+/μ^+ penetration length produces an error

- Error due to decay vertex resolution

Interaction	Probability uncertainty
Bremsstrahlung for positrons	0.038%
Annihilation for positrons	$\leq$0.010%
Photon conversion for both decays	0.010%
Total	0.041 %

$\boxed{\delta R_K/R_K = 0.00041}$

- Error due to material thickness uncertainty

Interaction	Relevant to	Correction error	$\Delta R_K/R_K$
Bremsstrahlung (rejected)	$\tilde{K}_{e2}$	0.003	2×10^{-4}
Annihilation in flight	$\tilde{K}_{e2}$	$\ll 10^{-4}$	$\ll 10^{-4}$
Photon conversion	$K_{e2\gamma}$, $K_{\mu 2\gamma}$	3×10^{-3}	$\sim 10^{-5}$
Total			2×10^{-4}

$\boxed{\delta R_K/R_K = 0.00020}$

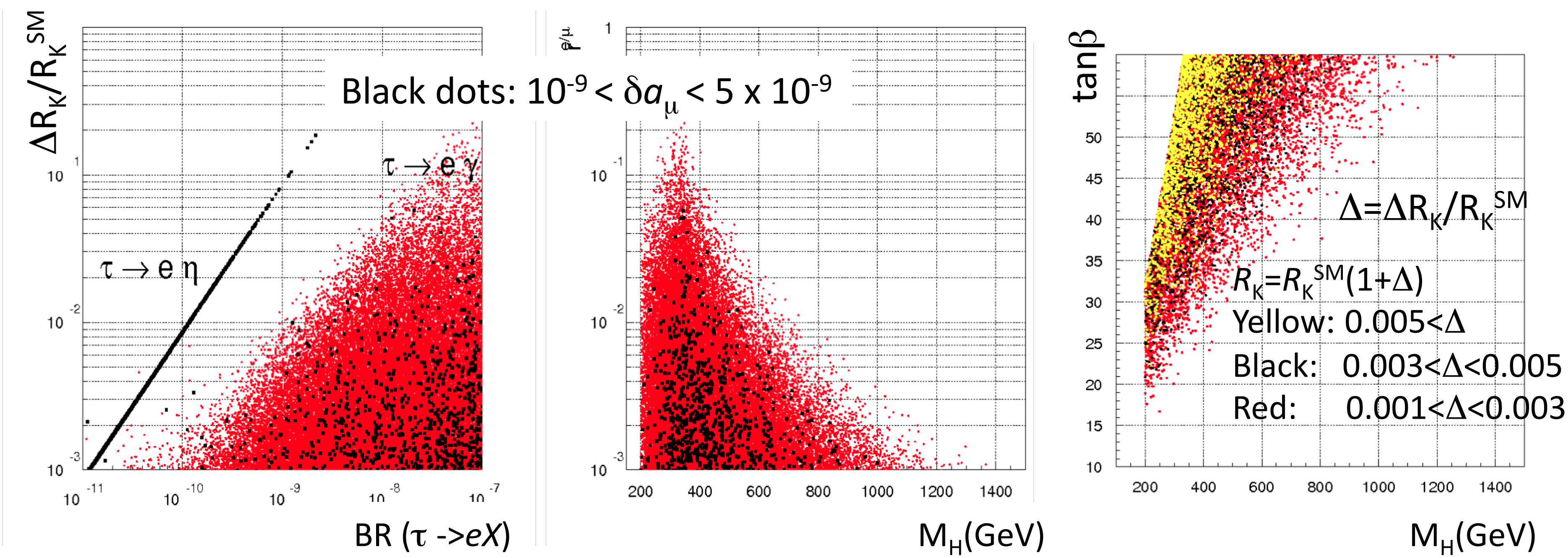
Error evaluation of R_K measurement using a stopped K^+ beam

$$\Gamma(K_{e2})/\Gamma(K_{\mu 2}) = \boxed{N(K_{e2})/N(K_{\mu 2})} \cdot \boxed{\Omega(K_{\mu 2})/\Omega(K_{e2})}.$$

- Structure dependent (SD) component of the radiative K_{l2} decay have to be subtracted from the observed events.
- Misunderstanding of K_{e2} event loss due to high energy bremsstrahlung photons induce wrong K_{e2} acceptance.
- e/μ misidentification can easily introduce R_K uncertainty.
- Tracker efficiency difference between e^+ and μ^+ also introduce some error.
- Others: in-flight muon decay, beam accidentals, photon conversion into $e^\pm$.

LFV in SUSY

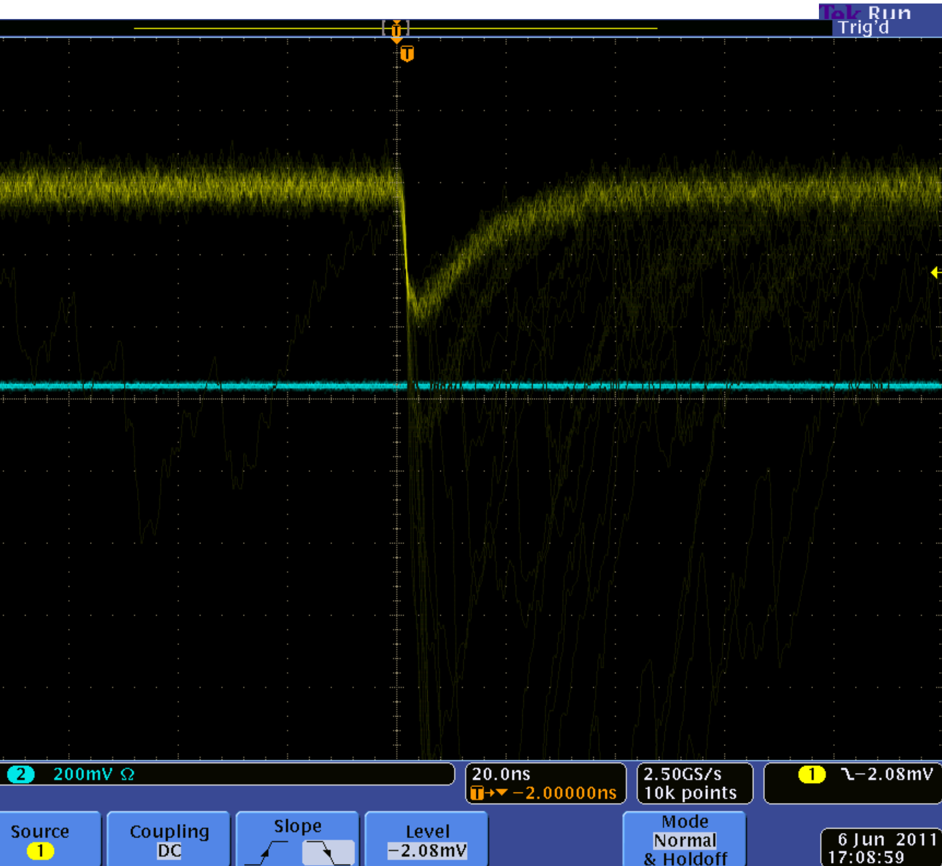
- LFV effect may be found in ΔR_K
- $\Delta R_K/R_K \approx 1\%$ corresponds to $BR\ (\tau \text{ -> } eX\ ) \leq 10^{-10}$
  - Strong correlation to $BR\ (\ \tau\text{-> } e\eta\ )$
  - Additive to R_K^{SM} (no interference: $R_K > R_K^{SM}$)
- Strong constraint on M_H for large $\tan\beta$ (equal to a_μ)



[Masiero, Paradisi and Petronzio; 2008]

MPPC Pulses

1 pe ~ 4 mV



Sr source ≤ 80 mV